Development and application of stressor – response relationships of nutrients

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Development and application of stressor – response relationships of nutrients

Doctoral Thesis

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Chapter 1

General introduction

1.1 Background

1.1.1 Abiotic and biotic effects of nutrient pollution

Among the chemical elements in the periodic table, nutrients are essential to the maintenance of living cells, as they constitute organic molecules such as nucleic acids, chlorophyll, and phospholipids. Some of these nutrients are required in high concentrations and are thereby named macronutrients, e.g. carbon, nitrogen, hydrogen, phosphorus, and sulfur (Millenium Ecosystem Assessment, 2005). Historical events, such as the industrial revolution, the intensification of agricultural production, and the increase in the population and resource consumption, have led to an unprecedented increase in the flows of carbon (IPCC, 1990), phosphorus (Cordell *et al.*, 2009), sulfur (Kuylenstierna *et al.*, 2001), and nitrogen (Bouwman *et al.*, 2009). Ultimately, the excess in nutrient availability has led to impacts on biodiversity.

Anthropogenic emissions of macronutrients cause increasing stressor levels in different environmental compartments. As a result of increasing fossil fuel combustion and land use change (IPCC, 1990), the surplus of carbon dioxide in the atmosphere and its subsequent deposition into oceans lead to increasing hydrogen ion concentrations and calcium carbonate dissolution in marine water (Feely *et al.*, 2009). Phosphorus and nitrogen emissions to freshwater, originating from wastewater (Van Drecht *et al.*, 2009a), agricultural runoff, and, in the case of nitrogen, atmospheric deposition (Bouwman *et al.*, 2009), lead to increasing net primary productivity and depletion of dissolved oxygen (Carpenter *et al.*, 1998). Likewise, nitrogen and sulfur compounds emitted to the atmosphere are deposited on land afterwards (Dentener *et al.*, 2006a) and, ultimately, they lead to increasing levels of hydrogen and aluminum ions and leaching of base cations in the soil (Warfvinge & Sverdrup, 1992).

The biogeochemical processes leading to the abiotic changes described above can be estimated on a global scale with spatially explicitly models, such as with Global NEWS or GEOS Chem (Bey *et al.*, 2001, Bouwman *et al.*, 2009). Nutrient pollution may trigger biotic effects, such as declines of growth and reproduction rates (Falkengren-Grerup, 1986, Zvereva *et al.*, 2010), increases in mortality rates (Kurihara *et al.*, 2004b), and changes in species composition (Carpenter *et al.*, 1998) and richness (Zvereva *et al.*, 2008). The mechanisms by which the surplus in stressor levels affects species are numerous. In the case of ocean acidification, calcifying organisms are subjected to declines in their calcareous body mass as a result of calcium carbonate dissolution (Feely *et al.*, 2009), thereby affecting their growth, reproduction and survival (Kurihara *et al.*, 2004b). On land, soil pH decreases affect the reproduction and growth of plants (Falkengren-Grerup, 1986, Zvereva *et al.*, 2010) and their richness (Zvereva *et al.*, 2008). In aquatic systems, increasing primary productivity can lead to the release of allelochemicals by competing phytoplankton and decreasing supply of oxygen, both of which may be harmful to freshwater species (Leflaive & Ten-Hage, 2007, Verberk *et al.*, 2011).

1.1.2 Life cycle assessment and risk assessment

The assessment of abiotic and biotic impacts of nutrient pollution can be performed by combining existing models on the transport of pollutants with quantitative relationships of their effects on species. Two possible methods by which this can be attained are life cycle impact assessment (LCIA) and environmental risk assessment (ERA). These are described below.

In order to evaluate the environmental impact of a given product or service, a life cycle assessment (LCA) can be performed (Udo de Haes *et al.*, 2002a). In the impact assessment phase of LCA, the impact of the emission of a pollutant on the ecosystem is described with a characterization factor (CF). The CF is composed of a fate factor, whereby the transport of the pollutant of concern from its emission to its receiving location is estimates, e.g. Helmes *et al.* (2012), Roy *et al.* (2012b), and an effect factor, which described the increase in ecosystem damage resulting from an increase in the concentration of the pollutant of concern in its receiving ecosystem. Recently, nutrient transport models were also developed within the context of life cycle assessment (LCA) on a global scale for phosphorus in inland waters (Helmes *et al.*, 2012) and nitrogen and sulfur in the atmospheric and soil compartments (Roy *et al.*, 2012a, Roy *et al.*, 2012b).

One approach for estimating the biotic effects of environmental pollution is with estimations of the ecological risk of a pollutant or group of pollutants (Fedorenkova *et al.*, 2012, van Straalen, 2002). These consist of the estimation of the risk that species are impacted as a result of exposure to a certain pollutant concentration in the environment. This risk takes into account the inherent range in tolerance of a species assemblage to the pollutant and the actual levels of the pollutant in the environment.

Unlike the CF, which estimates the environmental burden of an emission, the ecological risk approach estimates the ecological impact of a certain stressor in the environment (namely, its concentration). However, LCIA and ERA both employ stressor – response functions describing the impact of the concentration of a pollutant to a species group representative of a species assemblage in the environment.

1.1.3 Stressor – response functions and their underlying data

The cumulative effect of increasing nutrient pollution on an assemblage of species can be illustrated with a stressor – response function (Figure 1.1). This probabilistic model framework can be built from species sensitivity distributions of ecotoxicology (Posthuma *et al.*, 2002) and was extended to include ecological impacts due to nutrient pollution. The function may represent, for example, the increase in the fraction of species potentially affected (PAF) due to the increase of a stressor level. Likewise, the function can illustrate the decrease in the relative species richness (RSR) expected with increasing stressor levels.

Stressor – response functions can be derived using data collected in laboratory, under highly controlled conditions (Krewski *et al.*, 2009), as well as using data collected in the field, where variability in environmental conditions is more significant. Similarly to laboratory experiments, field experiments may be set up in order to test a specific hypothesis and hence their environmental variable of interest is manipulated. A famous example is nutrient addition experiments, which test if the excess of a nutrient enhances primary productivity (Schindler, 1977). These manipulated field experiments differ from observational field experiments as the latter often does not purposely modify the environmental variable of interest so as to test a hypothesis. The environmental variables, as well as the biotic response of interest, are thereby simply surveyed (Struijs *et al.*, 2011b).

Observational field experiments can be conducted at fairly lower costs compared with manipulated experiments. Besides this practical motivation, observational field experiments may more efficiently record the species in the field because they often do not specifically focus on a species or group of species beforehand and, accordingly, the inventoried species assemblage may be more representative than that of manipulated experiments. Finally, since manipulated experiments are perturbations of environmental variables so as to test a possible cause – effect relationship, they may overlook ecological processes which may begin long after the experiment has been terminated, thereby leading to misleading results or failure to detect differences among treatments (Tilman, 1987). For example, lakes may be subjected to long-term processes such as the uplift of phosphorus from sediments into the water column (Holtan *et al.*, 1988), which may not be detected if the experiment is short.

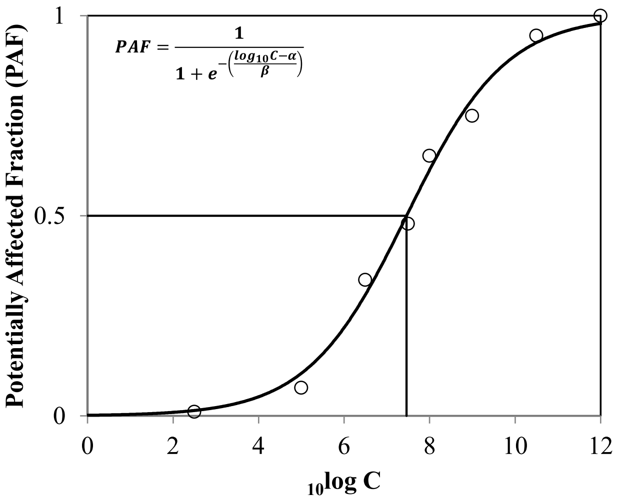

Figure 1.1 *Example of a logistic function describing the potentially affected fraction (PAF) of species as a function of concentration C (e.g., mg·L^{-1}) of stressor. The coefficients α and β of the PAF as a function of C represent the $_{10}$log concentration of C that prompts the PAF to equal 0.5 (in this case, α = 7.5) and the slope of the log-logistic function, respectively.*

1.2 Problem statement

Ecosystem-specific impact assessments of the biotic effects of nutrient pollution are common, e.g. Kozlov & Zvereva (2011), Bobbink *et al.* (2010), De Schrijver *et al.* (2011), particularly in temperate systems (Dodd *et al.*, 1994, Harpole & Tilman, 2007). Assessments of nutrient pollution impacts which are not differentiated across ecosystems have also been performed, e.g. for phosphorus eutrophication (Weijters *et al.*, 2009). Impact assessments with a focus on specific life processes as growth or mortality are relatively common (Elser *et al.*, 1996, Kurihara *et al.*, 2004b). Besides life processes, ecosystem-specific assessments based on species diversity losses following increasing levels of stressors such as eutrophication are also available on a global scale (Alkemade *et al.*, 2009, Bobbink *et al.*, 2010, Schuurkes *et al.*, 1986).

Nevertheless, large-scale assessments covering multiple ecosystems prompted by terrestrial and marine acidification or freshwater eutrophication are rare. This deficiency is also reflected in LCA and ERA, where the effects of pollutants on species diversity are available for a specific European ecosystems, e.g. forests (van Zelm *et al.*, 2007) or streams (Struijs *et al.*, 2011b). Furthermore, within the context of ERA, the impacts of nitrogen and phosphorus are generally performed for a single pollutant only. Additionally, in the case of nitrogen and phosphorus, assessments are either site-specific (Schindler, 2012, Schindler *et al.*, 2008) or they are performed on a global scale but without differentiation between world's regions (Weijters *et al.*, 2009). For ocean acidification, the impact of pH declines on species life processes have generally been conducted in laboratories, mesocosms and for a limited number of species only, e.g. Kurihara & Shirayama (2004) and Thomsen *et al.* (2013).

1.3 Thesis goal and outline

The goal of this thesis is to develop stressor – response relationships that allow for (1) comparisons of the relative impact of nutrient pollution across different regions, environmental compartments, or species groups, and (2) implementation into the context of LCA or ERA. To achieve this goal, relationships were developed for three categories of impact, i.e., terrestrial acidification, marine acidification, and freshwater eutrophication. Common features of these relationships were their large spatial coverages (i.e. continental or global) and the large numbers of species included in the relationships. An overview of the chapters of the thesis is given in Table 1.1.

Chapters 2 and 3 assess the impact of terrestrial acidification on vascular plant species based on observational field data. In chapter 2, the stressor – response relationships describe the changes in the relative species richness (RSR) following the changes in soil pH in multiple biogeographic regions (i.e. terrestrial biomes). In this chapter, the pH at which species richness is maximized and the coefficients of the stressor – response curves describing the effect of pH on RSR are compared across the biomes.

In chapter 3, the stressor – response curves are applied into the context of LCIA in order to estimate the relative impact of acidifying emissions on the potentially not occurring fraction (PNOF) of vascular plants. Here, the impact is calculated for individual grids (spatial resolution: 2.0 º x 2.5º) and it integrates the atmospheric fate of acidifying pollutants and the subsequent decrease in soil pH with the relationships between pH and PNOF.

In chapter 4, the stressor – response curves describe the changes in the potentially affected fraction (PAF) of calcifying species due to changes in marine water pH. Here, the relationships are developed on a global scale (thus, no spatial specificity) and for three life processes (i.e. mortality, reproduction, and growth) using data from controlled experiments. The relationships are then employed into the context of ERA in order to estimate the PAF and the increases in PAF with two different climate change scenarios for individual grids (spatial resolution: 4.0 º x 5.0 º).

Chapters 5, 6, and 7 assess the impact of freshwater eutrophication on different species groups based on observational field data. In chapter 5, the stressor – response relationships describe the changes in the RSR of autotrophs and heterotrophs following the changes in total phosphorus (TP) in multiple biogeographic regions (i.e. freshwater habitats) and in two freshwater types (i.e. lakes and streams). Similarly to chapter 1, the TP level that maximizes species richness and the coefficients of the stressor – response curves describing the effect of TP on RSR are compared across habitats or freshwater types.

In chapter 6, the stressor – response curves are applied into the context of LCIA in order to estimate the relative impact of phosphorus emissions to water on PNOF of heterotrophs. Here, the impact is calculated for individual grids (spatial resolution: 0.5º x 0.5º) and it is estimated with a transport model of TP in freshwaters and with an effect model of the increase in PNOF following an increase in TP levels. In this chapter, the impact of TP emissions occurring in temperate European river basins is compared across lakes and streams and across three effect model types that are available for LCIA.

In chapter 7, stressor – response curves are applied into the context of ERA in order to estimate the risk that increasing TP and NO_3 cause species to become absent. Here, the risk is calculated for individual river basins of Europe and it integrates monitored environmental concentrations of N and P of the last twenty-five years and stressor – response curves describing the additive effect of TP and NO_3 on the PNOF of invertebrates.

Table 1.1 *Overview of the stressor – response curved developed in each chapter*

Chapter	**Compartment**	**Category of impact**	**Stressor**	**Experiment type**	**Species group**	**Response type**	**Spatial coverage**	**Spatial resolution**	**Application**
2	Terrestrial	Acidification	pH	Observational	Vascular plants	Occurrence change	Global	Biome	Assessment of differences in ecosystem sensitivity
3	Terrestrial	Acidification	pH	Observational	Vascular plants	Occurrence decrease	Global	Biome	LCIA
4	Marine water	Acidification	pH	Controlled	Calcifying species	Growth, mortality, and decrease in reproduction	Global	Global	ERA
5	Freshwater	Eutrophication	TP	Observational	Heterotrophs and autotrophs	Occurrence change	Global	Biome	Assessment of differences in ecosystem sensitivity
6	Freshwater	Eutrophication	TP	Observational	Heterotrophs	Occurrence decrease	Temperate Europe	River basin	LCIA
7	Freshwater	Eutrophication	TP and NO_3	Observational	Invertebrates	Occurrence decrease	Temperate Europe	River basin	ERA

TP: total phosphorus; H: hydrogen ion; LCIA: Life Cycle Impact Assessment; ERA: Environmental Risk Assessment

Chapter 2

Global assessment of the effects of terrestrial acidification on plant species richness

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MODIFICATIONS FROM PUBLISHED VERSION

1- The dependent variable of the logistic regression is relative species richness (RSR), not potentially occurring fraction of species (PNOF);
2- Figures 2.1 and 2.2 are shown in grey scale, not in color;
3- The projection of the map of Figure 2.1 is Gall-Peters not Plate Carée;
4- The symbols if Figure 2.1 represent locations of studies, not individual study sites;
5- Figure S2.2.2 illustrate pH in soil profile for the four biomes of focus, not all.

ABSTRACT

This study estimates the potential losses of vascular plant species richness due to terrestrial acidification for different world's biomes. We used empirical occurrence data of 2409 species from 140 studies and estimated the relative species richness – pH response curves using logistic regressions. The regressions were then used to quantify the fraction of species that are potentially lost due to soil pH changes. Although we found considerable variability within biomes, out results show that the pH at which species richness was maximized was found to be the lowest in (sub)tropical forests (pH = 4.1) and the highest in deserts (pH = 7.4). We also found that (sub)tropical moist forests are highly sensitive to decreases of in soil pH below 4.1. This study can be coupled with existing atmospheric deposition models to quantify the risk of species richness loss following soil acidification.

2.1 Introduction

Terrestrial acidification is a global threat to plant diversity and is mainly caused by atmospheric deposition of acidifying compounds (Dentener *et al.*, 2006a). Soils of low pH or with low acid neutralizing capacity are generally characterized by increased mobilization and toxicity of aluminum and other metals, leaching of base cations, and decreased nitrification and organic matter decomposition rates (Bobbink *et al.*, 2010, Knoepp & Swank, 1994, Matson *et al.*, 1999).

As a result of changes in nutrient regulation, plants may suffer from a decrease in phosphorus and magnesium content in tissue, an increase in tissue yellowing, a reduction in biomass, coverage, and root growth, unsuccessful germination and regeneration, and competitive exclusion by acid-tolerant species (Falkengren-Grerup, 1986, Roem & Berendse, 2000, Zvereva *et al.*, 2008). Consequently, decreased occurrence of plants in unsuitable, acidified soils has been reported in areas subjected to soil pH reductions in the past (Falkengren-Grerup, 1986, Roem & Berendse, 2000).

Here we focus on soil pH as an indicator of soil acidity since it is an important predictor of plant occurrence and it is correlated to many soil nutrients, e.g. base cations, and acidifying pollutants, e.g. aluminum and sulfur (Kozlov & Zvereva, 2011, Peppler-Lisbach & Kleyer, 2009, van Zelm *et al.*, 2007).

Up to now, studies that relate soil pH with species richness have included only a limited number of ecosystems, most of which are in middle to high latitudes (Chytrý *et al.*, 2010, Olsson *et al.*, 2009). Recently, climate has been shown to be an important predictor of the sensitivity of vascular plants to various pollutants (Kozlov & Zvereva, 2011). In warmer climates, for example, higher temperatures may increase the mobility of toxicants and the year-round production of tissue may enhance sensitivity to pollutants (Zvereva *et al.*, 2008). In addition, larger plants or plants consisting of woody tissue appear to be more sensitive to acidifying pollution than small, soft tissue ones (Zvereva *et al.*, 2010, Zvereva *et al.*, 2008).

To identify large regions according to their climate and ecological interactions and similarities (Orians, 1993), this study categorized the world into terrestrial biomes delineated by Olson *et al.* (2001). Classification on a biome level highlights the influence of soil pH while accounting for main climatic differences such as temperature, precipitation, or sunlight.

The objective of our work is to develop response relationships of vascular species richness along the pH gradient for different world's biomes. The response relationships were attained for the acidic pH gradient, up to levels where vascular species richness is maximized. Here we define species richness as the total number of vascular species (trees, herbs, shrubs, etc.) occurring on a soil of a given soil pH. Vascular plants are important not only because they comprise a vast number of species of plants but also due to their contribution to a considerable portion of primary production in the terrestrial system. Response relationships of species richness and pH can be used for predictions of the potential reductions of biodiversity due to soil property changes (van Zelm *et al.*, 2007). Connecting pH response curves to pollutant transport models, including their impacts on soil properties, may give insight into the impact of acidifying pollution at large spatial scales, help identify sensitive areas, and indicate where acidifying pollution reduction efforts should be concentrated (Mac Nally & Fleishman, 2004, van Zelm *et al.*, 2007).

2.2 Material and methods

In order to estimate the relative vascular plant species richness – pH patterns, we first gathered field observational data from the literature relating individual species occurrence and soil pH to derive empirical relationships of species richness along the soil pH gradient. Second, we performed a logistic regression analysis to arrive at pH – response functions for the different biomes. The steps of gathering literature data to finally determining response functions are described below and illustrated in appendix S2.1 of the Supporting Information.

2.2.1 Data gathering

We collected peer-reviewed studies available up to September 2010 consulting Web of Science with the following keywords: (1) pH; and (2) either soil, ground, land, or terrestrial; and (3) either cover, abundance, species richness, species frequency, extinction, presence, absence, diversity, biodiversity, community, occurrence, or biomass; and (4) either plantation, plant, plants, vegetation, vegetative, flora, forest, tree, or trees. This keyword combination allowed the retrieval of approximately 4000 peer-reviewed studies that were considered for our data inventory. We then manually selected the studies that fulfilled the following criteria.

We excluded croplands or urban studies as they do not reflect the natural vegetation of the area and included studies based on abandoned, restored, re-vegetated areas, and semi-natural grasslands since they are also subjected to biodiversity losses due to terrestrial acidification. Additionally, we only included exploratory, survey studies that reported a specific quantitative relationship between pH and vascular plant species. We only considered species and not higher taxonomic groups (e.g. family, class, etc.). An exception was made for genus-level records when those did not accompany any other species belonging to that genus. Lower taxonomic level records (i.e. subspecies, variety) were also included and were considered equal to a species record.

2.2.2 Data handling

First, pH values were standardized to a representative soil depth and to water extracted pH (pH-H_2O). When more than one pH was reported for a given soil (e.g. multiple horizons), we used the value that was closest to either the B horizon or to 50cm of soil depth. This is the soil horizon where there is accumulation of clay minerals such as iron and aluminum and the approximate depth at which roots are present in all biomes (Canadell *et al.*, 1996). For the studies reporting soil pH by KCl or $CaCl_2$ and not by H_2O extraction (fifteen in total), we converted pH – KCl and pH – $CaCl_2$ values to pH-H_2O using data from the ISRIC-World Soil Information database (Batjes, 2009), appendix S2.2.

Second, we standardized the species name records using The Plant List (2010) so as to correct for synonyms. Since species occurrence was reported in different ways (i.e. biomass, percent cover, abundance) we adapted the data to a presence or absence format by transforming any number higher than zero to species presence and any zero value to species absence.

Subsequently, we allocated each of the selected studies to one of the biomes based on the vegetation coverage described by their authors. Studies describing a vegetation pattern that either did not fit the biome classification system described by Olson *et al.* (2001) or that were described as a transition zone between two biomes were excluded.

Following this, we derived the pH range at which each plant species can occur within the biome. We considered a species to be absent at pH values outside its reported pH range. The soil pH range obtained from each study was set equal to the mean pH ± 1.645 times the reported standard deviation (i.e. 90% of sample population) following Latour *et al.* (1994). For forty studies that did not report mean and standard deviation values, but the minimum – maximum pH ranges were used instead, e.g. Karim & Mallik (2008). Finally, we determined the range between the minimum and maximum pH of each specific plant species per biome as the pH occurrence range for that species. If a species was reported in more than one study within the same biome, we used the lower and upper pH boundaries as the overall species occurrence range. From the pH occurrence ranges of the species within each biome, we excluded the species that were reported at a single mean pH value (273 of 3311 species – biome combinations) because these data are not representative of the tolerance pH range where a species is found in the environment.

2.2.3 Response curves

We computed the species richness (SR) as the sum of present species at each 0.1 pH unit *i* value within each biome *j* as

Soil pH – relative species richness

$$SR_{i,j} = \sum pH_{i,j} O_{i,j} \tag{2.1}$$

where O is the occurrence of each species at pH *i* in biome *j*. O is 0 when the species was reported absent and 1 if the species was reported present.

In a subsequent step, so as to compare biomes with dissimilar species richness, e.g. temperate vs. (sub)tropical forest, the species richness results in each biome were transformed into a zero-to-one measure described as the empirical relative species richness (eRSR) as

$$eRSR_{i,j} = 1 - \frac{SR_{i,j}}{SR_{opt,j}}, \text{ for } pH_{i,j} \leq pH_{opt,j} \tag{2.2}$$

where $SR_{i,j}$ is the number of species present at pH *i* and $S_{opt,j}$ is the highest species richness along the pH gradient of biome *j*. An eRSR of one represents the optimum pH condition ($pH_{opt,j}$) or optimum pH conditions (range of pH_{opt}), where species richness equals $SR_{opt,j}$; while an eRSR of one represents the complete absence of species.

We calculated logistic functions of RSR (cRSR) by fitting them to the empirical eRSR data. The use of logistic functions follows the calculation procedure commonly adopted in ecotoxicology to arrive at species sensitivity distributions for toxic chemicals and population modeling studies (De Zwart, 2001). They are represented as

$$eRSR_{i,j} = \frac{1}{1+e^{-\frac{(pH_{i,j}-\alpha_j)}{\beta_j}}}, \text{ for } pH_{i,j} \leq pH_{opt,j} \tag{2.3}$$

where $cRSR_{i,j}$ is the calculated RSR at pH *i* of biome *j* below or equal to $pH_{opt,j}$ (equation 2.3). At pH levels above pH_{opt}, species richness is not affected by acidic soil conditions but by other stressors, which we do not account in this study, such as sodium toxicity, etc. Coefficient α represents the pH at which the relative species richness is 0.5 and β represents the relative change in species richness with pH. Biomes with low β values comprise the ecosystems with the steepest slope in the logistic function. We fitted α and β coefficients using logistic regression in SAS 9.2. The sample size for cRSR is given by the number of cRSR – pH data points (with a 0.1 pH interval) observed from the lower end of the pH gradient up until the pH optimum. The confidence intervals were reported at a 95% confidence level.

2.2.4 Sensitivity analysis

In order to evaluate the uncertainty in the pH-response curves within biomes, we performed a sensitivity analysis for two additional levels of spatial aggregation: Ecoregion and individual sites (study) within each biome. That was attained by allocating the studies to ecoregions instead of biomes (Olson *et al.*, 2001). Ecoregions are biogeographical subunits of specific biomes thus they offer a higher resolution of the existing vegetation. We then used the same methodology as described above and derived ecoregion-specific and site-specific logistic functions.

2.3 Results

A total of 140 studies fulfilled our selection criteria (appendix S2.3) which, in total, comprised 2409 vascular plant species (see Table S2.4.2., appendix S2.4, for their respective pH range within each biome). The number of studies within biomes varied from 2 (i.e. flooded grasslands and savanna, mangrove, and montane grassland and shrubland) to 55 (temperate broadleaf mixed forest), Table 2.1. The location of each study is shown in Figure 2.1.

In (sub)tropical moist broadleaf forests, the optimum pH was the lowest (4.1) while in desert and xeric shrublands and mediterranean forests, woodland and scrub, the optimum pH was the highest (7.4 to 7.8). Biomes within the temperate zone have rather similar optimum pHs, i.e. broadleaf mixed and coniferous forests, and grassland, savanna, and shrubland (4.7 to 5.1). The logistic regressions for all biomes indicate an association between decreasing RSR and pH decreasing (Figure 2.2).

Our results show that (sub)tropical moist broadleaf forest have steep cRSR slopes (β = 0.18 to 0.25, Table 2.2). This indicates that terrestrial acidification could cause the highest decreases in RSR (thus the steepest species loss) in that biome.

Studies were available for a total of fifty-six ecoregions distributed across the thirteen biomes for comparisons of different spatial aggregation levels, (Table S2.5.1, appendix S2.5) and we were able to derive logistic functions for nineteen of them (Table S2.5.2, appendix S2.5). At a site (i.e. study) spatial resolution, we were able to derive logistic functions for thirty-three out of 140 individual studies (Table S2.5.3, appendix S2.5). We found higher optimum pHs for ecoregions (from 7.0 to 7.5) and sites (from 7.0 to 8.3) within desert and xeric shrubland compared to temperate broadleaf mixed forest and (sub)tropical moist broadleaf forests, which varied from 4.0 to 7.2 at the ecoregion level and 4.0 to 7.5 at the site level. Likewise, α

coefficients were consistently higher in desert and xeric shrublands (from 6.2 to 8.3) compared to temperate broadleaf mixed forest and (sub)tropical moist broadleaf forest (from 3.1 to 6.1). However, no difference was observed in β results across biomes at the ecoregion and site spatial resolution level.

Table 2.1 *Total numbers of studies and species per biome, the total number of species in the optimum pH, the pH range of species occurrence and the (range of) optimum pH.*

Biome	**Studies**	**Species**	**Species in the optimum pH ($SR_{opt,j}$)**	**pH range**	**(Range of) pH optimum**
(Sub)tropical Moist Broadleaf Forest	17	533	358	3 to 8.2	4.1
(Sub)tropical grassland, savanna, and shrubland	3	131	107	4.5 to 6.1	4.9
Mangrove	2	25	25	3.4 to 7.2	4.3 to 6.0
(Sub)tropical dry broadleaf forest	3	139	65	5.5 to 8.5	7
Flooded grassland and savanna	2	18	18	5.3 to 6.9	5.9 to 6.6
Desert and xeric shrubland	17	350	293	5.1 to 10.5	7.4
Mediterranean Forest, Woodland, and Shrubland	4	31	13	4.9 to 8.6	7.8
Temperate Broadleaf Mixed Forest	55	682	473	2.4 to 9.4	4.7 to 5.1
Temperate Grassland, Savanna, and Shrubland	17	422	325	2.6 to 9.1	5.1 to 5.7
Temperate Coniferous Forest	8	230	191	3.1 to 8.3	4.7 to 4.8
Montane grassland and shrubland	2	138	138	5.5 to 7	6.0 to 7.0
Boreal Forest / Taiga	4	90	77	3.2 to 7.7	5.3
Tundra and alpine	6	171	111	4 to 7.9	7.0 to 7.3

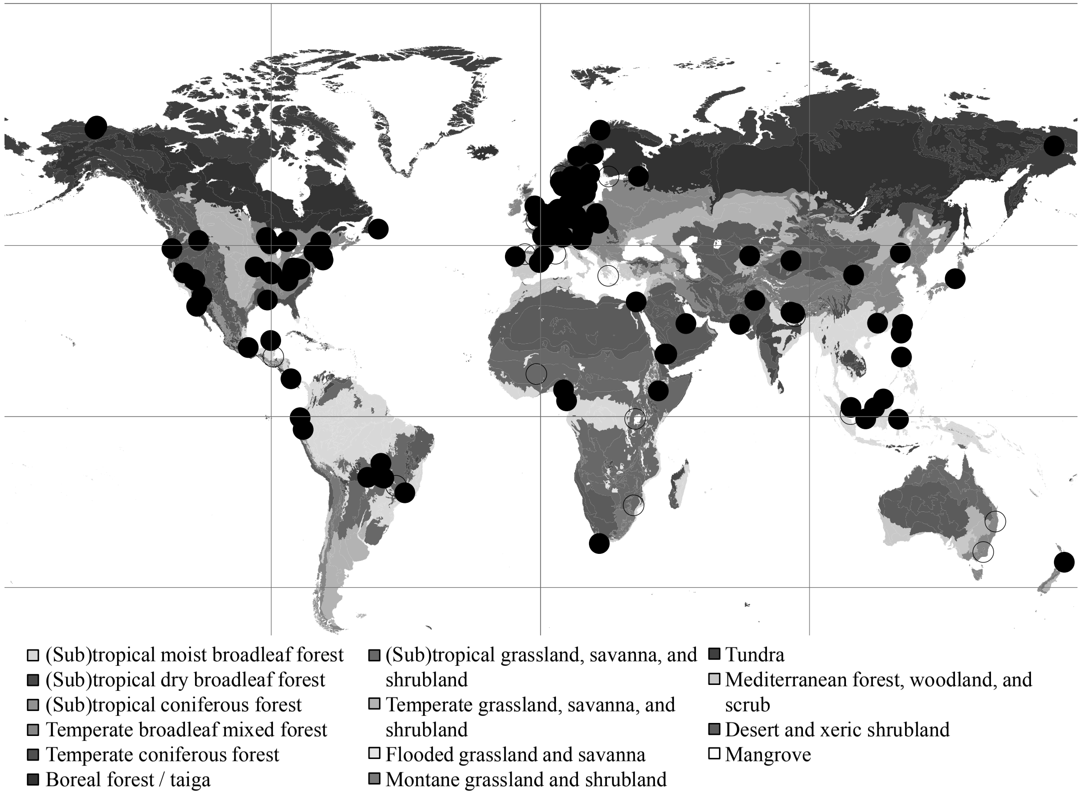

Figure 2.1 *Biomes delineated by Olson et al. (2001) and the location of the 136 studies included in our paper. The sites where the described vegetation in each study corresponds to the biome where it is located (total of 118) and where the described vegetation is outside the boundaries of the corresponding biome (total of 16) are represented by closed and open circles, respectively.*

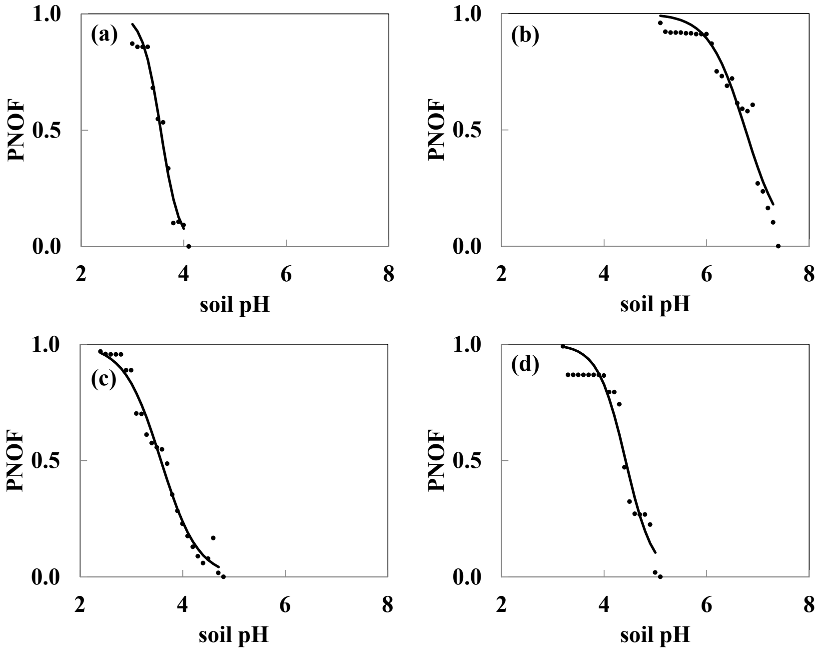

*Figure 2.2 Examples of response curves for the relative species richness (RSR) of plants along the soil pH range shown for **(a)** (sub)tropical moist broadleaf forest, **(b)** desert and xeric shrubland, **(c)** temperate broadleaf mixed forest, and **(d)** temperate grassland, savanna, and shrubland. Dots and lines represent, respectively, the empirical (eRSR) and the calculated (cRSR).*

2.4 Discussion

We predicted the relative vascular plant species richness – soil pH patterns, expressed as RSR, aggregated at the ecosystem (biome) level. In the following, we discuss the sources of uncertainty involved in our study. Furthermore, we assess the validity of our results by suggesting ecological arguments for the differences in the PNOF – pH relationships across ecosystems.

2.4.1 Uncertainty

First, it should be stressed that the RSR reveals relative changes in overall vascular plants richness but not in individual species. Also, we do not analyze differentiated responses of specific functional traits, of specific native plants, or taxonomic groups. Hence, designating an optimum (or range of optimum) pH based on the maximized number of species may not necessarily associate with the least modified, most "pristine" soil condition.

Our results should thus be interpreted at the community level instead of at the species level.

Secondly, the number of studies differed considerably across biomes, which affected the number of species available in each biome (Table 2.1). For example, despite the high biodiversity in (sub)tropical biomes, we found more species reported in the temperate broadleaf mixed forest biome (Table 2.1). Given the low number of species available to derive logistic regressions in poorly covered biomes (e.g. mangroves, mediterranean forest, woodland, and scrub, and flooded grassland and savanna), the results for these biomes should be interpreted with caution. Therefore, interpretation is focused on biomes which are better covered by a number of studies and species.

Thirdly, for the temperate broadleaf mixed forest biome especially, there were a large number of European studies found. Given that we clustered all the studies into the same biogeographical region, there may be an over-representation of European species in this biome.

A fourth source of uncertainty is that our regressions were based on empirical data reporting the occurrence of plant species at a particular pH range. Our assumption is that, outside that range, the species was not observed thus it may have become absent.. Within the pH occurrence range, the species is always considered to be present. Ultimately, in our field-based study, species absence could have been due to an unreported species occurrence outside the pH boundaries. Our approach differs from controlled, laboratory-based standard species sensitivity distributions, where the environmental conditions and the species of interest are deliberately chosen (Posthuma *et al.*, 2002, Tilman, 1987). In controlled studies, conditions that determine species presence can be ascertained with a higher level of certainty. If the ranges of species occurrence were broader than what we were able to determine, the species richness would be maintained at lower pH conditions. Accordingly, the pH level where RSR is 0.5 would be lower than those currently reported.

Fifth, the conversion of pH-KCl and pH-$CaCl_2$ to pH-H_2O could have introduced uncertainty to the range of pH occurrence of each species. The conversion from $CaCl_2$ and KCl to H_2O extracted pH varied up to 1 and 2 pH units, respectively (appendix S2.2). This uncertainty may have been larger in temperate grassland, savanna, and shrubland and temperate broadleaf mixed forest biomes, where 17 to 20% of studies required conversion. Desert and xeric shrublands required no conversion to H_2O-extraction.

Table 2.2 *Logistic regressions coefficients α and β (95% confidence interval) for the RSR curves.*

Biome	**α**	**β**	**R^{2}**[¶]
(Sub)Tropical Moist Broadleaf Forest	3.55 (3.51 to 3.6)	0.18 (0.14 to 0.22)	0.97
(Sub)tropical grassland, savanna, and shrubland[#]	4.55 (4.40 to 4.70)	0.16 (NS)	
Mangrove	3.72 (3.67 to 3.77)	0.25 (0.20 to 0.30)	0.95
(Sub)tropical dry broadleaf forest	Model did not fit the empirical data		
Flooded grassland and savanna	5.31 (5.10 to 5.51)	0.33 (0.14 to 0.53)	0.73
Desert and xeric shrubland	6.76 (6.68 to 6.83)	0.36 (0.28 to 0.36)	0.94
Mediterranean Forest, Woodland, and Shrubland	6.64 (6.21 to 7.08)	1.18 (0.54 to 1.83)	0.42
Temperate Broadleaf Mixed Forest	3.57 (3.53 to 3.61)	0.36 (0.32 to 0.40)	0.98
Temperate Grassland, Savanna, and Shrubland	4.42 (4.37 to 4.47)	0.26 (0.22 to 0.31)	0.95
Temperate Coniferous Forest	3.33 (3.17 to 3.50)	0.28 (0.11 to 0.44)	0.65
Montane grassland and shrubland[#]	5.92 (NS)	0.01 (NS)	
Boreal Forest / Taiga	4.21 (4.09 to 4.32)	0.69 (0.55 to 0.84)	0.89
Tundra and alpine	4.76 (4.62 to 4.90)	0.47 (0.33 to 0.61)	0.86

[#] One (or both) logistic coefficients are non-significant at a 95% confidence level

[#] $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{corrected}}$, as defined by Schabenberger & Pierce (2001)

Our data set encompasses present-time, exploratory species occurrence studies of the last 20 years. Since acidifying pollution began much earlier than this, we cannot account for potential adaptation strategies that plants may have developed prior to the modification of the environment, e.g. increase in β-diversity, even though such adaptations are known to exist (Kozlov & Zvereva, 2011, Trubina & Vorobeichik, 2012). Also, a biome located in an area that has been exposed to intense air pollution, e.g. temperate broadleaf mixed forests, may have species that are less representative of their original assemblage or may have optimum pH lower than prior to air pollution compared to biomes which were subjected to acid deposition. Availability of nutrients such as nitrogen and phosphorus, which also relates to soil pH, may explain part of the remaining co-variance (Roem & Berendse, 2000).

Finally, the log-logistic results at the ecoregion and site spatial resolutions showed that there can be major differences between the logistic regression results representing plant communities of a biome. This may be remedied by applying more spatial to derive the regressions. However, this approach would include considerably fewer species per spatial unit and a reduced range of pH where species occur. Consequently, the logistic regression we proposed often did not fit the empirical data at an increasing level of spatial resolution. This inherent spatial variability may also be explained by the existence of ecoregions transitioning between two ecosystems, e.g. the Central forest-grassland transition ecoregion, or of studies corresponding to a certain biome but that are located within the boundaries of another biome (open circles in Figure 2.1). In these cases, the studies were allocated to biomes based on their vegetation description, not their position in the map.

2.4.2 Response curves

The differences in the pH optima and the response curves across biomes may be explained by intrinsic differences across biomes. Soil pH follows a latitudinal gradient in which the highest pH values occur at mid-latitudes (approximately 30º distant from the Equator line) while the lowest pH values occur in tropical regions (Pärtel, 2002), Figure S2.2.2. This trend is similar for the optimum pH of biomes found in this study (Table 2.1). For example, the highest optimum pH is observed in soils of deserts and xeric shrublands, which are subjected to low precipitation and cation accumulation combined with high soil evaporation (Smith *et al.*, 2002). Intermediately, mid to high latitude biomes, located in the temperate zone, are subjected to continuous sediment deposition from glaciations, e.g. temperate grassland, savanna, and shrubland (Pärtel, 2002). Conversely, (sub)tropical moist forests, generally comprising "ancient" soils, have low soil pH because they are subjected to strong long-term weathering of base cations without additional input of nutrient-rich sediments, in addition to increased solubility of ammonium, aluminum and manganese (Matson *et al.*, 1999).

The adaptation of plants to specific environmental conditions for which they have been subjected is explained by the species pool hypothesis (Hajek *et al.*, 2007, Pärtel, 2002). Species richness is maximized at low pH values in traditionally low soil pH biomes and at high pH values in traditionally high soil pH biomes (Chytrý *et al.*, 2010, Pärtel, 2002). For example, in southwestern African desert, the highest number of species was found between pH levels of 7.0 to 7.5 (Medinski *et al.*, 2010) while in the Appalachian Mountains, comprising temperate broadleaf mixed forests, maximum species richness is found at a pH of 4.0 to 5.0 (Peet *et al.*, 2003). The high tolerance to acidic conditions in (sub)tropical moist broadleaf forests is also reflected by the high incidence of species belonging to families that are known to comprise a large number of aluminum-tolerant plants, i.e. Melastomataceae, Theaceae, and Symplocaceae (Hayde Gonzalez-Santana *et al.*, 2012).

Species richness – soil pH relationships are often reported as linear (Schuster & Diekmann, 2003). However, even though there is an increasing fraction of species that perish with decreasing pH, this rate is reduced at increasingly acidic conditions, suggesting that the species richness – pH relationship is non-linear. While species that cannot sustain acidic conditions are reduced, the total number of species is still maintained by a few 'specialist' species that are able to sustain (or exist exclusively) at acidic conditions or that are able to adapt to new conditions, such as grasses (Falkengren-Grerup, 1986, Kozlov & Zvereva, 2011).

Although we found that (sub)tropical moist forests hold the highest number of species at acidic conditions, they are also highly sensitive to further increases in acidity compared to other biomes. This is illustrated by the steeper slope (lower β coefficient) of the log-logistic function, which represents the change in sensitivity associated with variation in soil pH.

Two aspects (the size and the physiology of plants) may help to explain the difference in the sensitivity of biomes to acidifying conditions. Previous studies report that grasses and smaller plants (herbaceous) are less sensitive to pollutants (e.g. aluminum or SO_2) than larger plants (Zvereva *et al.*, 2010, Zvereva *et al.*, 2008). Broadleaf mixed forests and grassland, savanna, and shrublands in the temperate zone were comprised of a high number of grasses and sedges (species of the Cyperaceae, Juncaceae, and Poaceae families). Small size plants, which are adapted to lessen evapotranspiration, dominated the desert and xeric shrubland biome, e.g. species of the Amaranthaceae and Cactaceae families. (Sub)tropical moist forests, on the other hand, encompassed large evergreen trees, e.g. Lauraceae, Myrtaceae species.

Toxic levels triggered by acidic conditions are particularly harmful to young roots (Zvereva *et al.*, 2008). In addition, roots tend to grow to deeper layers in arid soils (Wilcox *et al.*, 2004), which may become less exposed to the deposition of acidifying compounds. In opposition to colder (higher latitude) biomes, the high rate and year-round production of plant tissue in (sub)tropical moist forests may increase tissue exposure to acidic conditions and increase their sensitivity to low pH conditions. Mangroves, likewise, may be exposed to heavy metals following oxygenation of iron sulfide-rich soils (Amaral *et al.*, 2011). The decreasing sensitivity to pollution with increasing latitude and decreasing temperature and precipitation has been observed in previous meta-analysis studies (Zvereva *et al.*, 2010, Zvereva *et al.*, 2008).

2.5 Conclusion

The results of this study describe general patterns that illustrate the increase in the fraction of species that may disappear with acidifying conditions at a spatial resolution equivalent to biomes. When a sensitivity analysis at higher spatial resolutions was performed (ecoregions and individual sites), we identified a considerable spatial variability within biomes, especially in the slope (β) of the logistic regressions, β. Furthermore, the results relating to many biomes were based on a small number of available species due to the low availability of studies performed in these regions. In this study, we used biomes as the spatial resolution since enhancing geographical coverage can increase the explanatory power of biogeographical patterns such as species richness – pH relationships (Field *et al.*, 2009).

Our results suggest that regions within the (sub)tropical moist broadleaf forest may suffer great changes in species richness following a soil acidification. This is an alarming situation given that soils in the (sub)tropical climate zone have very low acid neutralizing capacity (Dentener *et al.*, 2006b, Kuylenstierna *et al.*, 2001). The results of our study can be used with atmospheric pollutant transport and soil fate models so as to link acidifying air emissions to their ultimate biodiversity risk.

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Chapter 3

Characterization factors for terrestrial acidification: a systematic analysis of spatial variability and uncertainty on a global scale

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Submitted

ABSTRACT

Characterization factors (CFs) that quantify the impact of acidifying emissions on the richness of terrestrial plant species in life cycle assessment (LCA) are currently available on a European continental level only. This paper provides 2^o x 2.5^o spatially-explicit CFs for terrestrial acidification by emissions of nitrogen oxides (NO_x), ammonia (NH_3) and sulphur dioxide (SO_2) at the global scale. The CF quantifies the change in relative loss of terrestrial plant species due to acidic pH due to an acidifying emission change. The CF considers the change in atmospheric acid deposition due to an emission change (atmospheric fate factor) which, according to the soil buffer capacity, increase the soil solution H^+ concentration (soil sensitivity factor) which, in turn, may lead to a loss in relative vascular plant species richness (effect factor). Emission locations in central Asia, central Africa and Canada were shown to have the highest consequences on terrestrial acidification. We found that the soil sensitivity factor is the dominant contributor to spatial variability in the CFs and that is over six orders of magnitude. The CFs provided in our study allows the worldwide spatially explicit evaluation of impacts related to acidifying emissions on the relative loss of vascular terrestrial plant species for a LCIA purposes. This opens the door to evaluating the regional life cycle emissions of different products in a global economy.

3.1 Introduction

Terrestrial acidification is the result of atmospheric acidifying emissions such as nitrogen oxides (NO_x), ammonia (NH_3) and sulphur dioxide (SO_2) and their subsequent deposition on soils, which may in turn decrease the soil's solution pH. A large pH deviation will impact the relative loss of plant species of terrestrial ecosystems (Thomsen *et al.*, 2013).

Global scale terrestrial acidification impact evaluation has thus far focused on a receptor's framework by evaluating the level of acid deposits (Volkoff, 1998), the receptor sensitivity with a critical load approach (Bouwman *et al.*, 2002, Kuylenstierna *et al.*, 2001) or, more recently, by quantifying an increase of H^+ ions in the soil solution, on a specific surface, following acid deposition (Roy *et al.*, 2012a). This paper integrates atmospheric source-receptor relationships (shifting the perspective from receptor to source location), subsequent proton soil solution increases, and finally changes in relative species richness due to acidifying effects.

Life cycle assessment (LCA) evaluates the potential impacts of a product or service throughout its life cycle (Udo de Haes *et al.*, 2002a). The potential environmental impacts of a given life cycle emission inventory are assessed using characterization factors (CFs). Endpoint level CFs are a mathematical representation of the cause-effect chain that links an emission to the ultimate impact of a given area of protection, e.g. human health, biodiversity loss (Udo de Haes *et al.*, 2002a). Historically, LCA evaluated potential impacts in a standardized or generic *unit world* and with simplified modeling of a typical pollutant's fate, exposure, and effect pattern (Chan & Connolly, 2013). However, Potting *et al.* (1998a) showed that source location and surrounding conditions strongly influenced CFs. Therefore, developments shifted to country- or continent-dependent CFs representative of certain regions, such as Europe, the United States or Japan (Bare, 2002, Goedkoop & Spriensma, 2001, Hayashi *et al.*, 2004, Huijbregts *et al.*, 2000, Potting *et al.*, 1998b, Seppälä *et al.*, 2006, van Zelm *et al.*, 2007). Yet, applying existing CFs implicitly assumes that every emission in the life cycle inventory of a product occurs in the specified region, which is not the case in our global market economy. Up to now, there is no spatially-explicit CFs for terrestrial acidification at the global scale.

Furthermore, current CFs do not account for the transport and sensitivity of acidifying emissions outside the considered geographical context. Neglecting transboundary transport to areas with limited buffer capacity (i.e. sensitive areas) may result in a large underestimation of CFs. Finally, while the spatial variability of CFs in many impact categories, including acidification, has been evaluated (Orr *et al.*, 2005), uncertainties, arising from not knowing exact model input parameters, are seldom considered in CF calculations. It has, however, been recognized that uncertainty evaluation is required in order to support LCA results interpretation (Finnveden *et al.*, 2009).

The objective of this paper is to develop spatially-explicit CFs for NO_x, NH_3 and SO_2 at the global scale with a spatial resolution of 2^o x 2.5^o (latitude x longitude) that includes atmospheric fate, soil sensitivity, and relative loss of plant species. In this context, we evaluate the importance of transboundary transport to the CFs and the contribution of atmospheric fate, soil sensitivity, and ecological effects to the spatial variability and parameter uncertainty of CFs.

3.2 Material and methods

3.2.1 Characterization factor

Building on the work of van Zelm *et al.* (2007), CFs for terrestrial acidification were defined as a change in the potentially not occurring fraction of vascular plant species (PNOF) summed over the receiving areas *j*, due to a marginal change in the emission of acidifying substance *p* at the source location *i*. The mathematical expression to convert atmospheric emissions of acidifying substances into a relative species loss indicator is presented in Equation 3.1. The CF can be subdivided into an atmospheric fate factor (FF), a soil sensitivity factor (SF) and a marginal effect factor (MEF). CFs ($m^2 \cdot yr \cdot kg^{-1}$) and were calculated for 13,104 emission source grids (2^o x 2.5^o spatial resolution) as

$$CF_{i,p} = \sum_j \left(FF_{i,j,p} \cdot SF_{j,p} \cdot MEF_j \right) \tag{3.1}$$

3.2.2 Atmospheric and soil sensitivity fate factor

The atmospheric fate factor (FF, $k_{eq} \cdot kg^{-1}$) describes the change in pollutant emission ($kg \cdot yr^{-1}$) in source grid cell *i* of acidifying pollutant *p* (i.e., NO_x, NH_3, or SO_2) and the change in acid deposition on soil *j (*$keq \cdot yr^{-1}$) in the receptor grid cell [see Roy *et al.* (2012b) for a detailed description of FFs], a spatial resolution of 2.0 x 2.5^o. The atmospheric transport is based on the 3-dimension GEOS-Chem global tropospheric chemistry model (Bey *et al.*, 2001), fed by meteorological observations from the Goddard Earth Observing System (GEOS) of the NASA Data Assimilation Office (Bey *et al.*, 2001). The yearly averaged results of GEOS-Chem for 2005 were used (2005 being representative of meteorology of the average from 1961 to 1990.

3.2.3 Soil sensitivity factor

The soil sensitivity factor (SF, mol $H \cdot L^{-1} \cdot m^2 \cdot keq^{-1} \cdot yr$) describes the change in soil solution hydrogen ion concentration (mol $H \cdot L^{-1}$) due to a change in the atmospheric deposits of pollutant *p* on soil *j (*$m^2 \cdot keq^{-1} \cdot yr$) in the receptor grid cell [see Roy *et al.* (2012a) for a detailed description of SFs]. We introduced changes in pollutant deposition from a 10% increase in emissions-depositions, which is commonly used to calculate CFs for acidification (Huijbregts *et al.*, 2000, Krewitt *et al.*, 2001, Potting *et al.*, 1998b). The SFs were determined with the steady-state PROFILE soil model.

3.2.4 Marginal effect factor

The effect factor was calculated by using biome-specific stressor – response relationships of the potentially not occurring fraction (PNOF) of vascular plant species and soil pH. To attain that, first, we considered the minimum pH value at which each species was confirmed to occur per biome (according to biome classification of Olson *et al.* (2001). Second, the empirical PNOF (ePNOF) was defined as the rank of the species divided by the maximum rank of the species within the biome. Third, we fitted the ePNOF as

$$PNOF_{j,b} = \frac{1_j}{1+e^{-\frac{log_{10}C_j-\alpha_j}{\beta_b}}} \tag{3.2}$$

where $PNOF_{j,b}$ is the potentially not occurring fraction of vascular plant species of biome *b* associated with soil *j*, C_j the soil H concentration, α_b represents the soil solution pH at which 50% of vascular plant species potentially do not occur in biome *b*, and β_b is the slope of the logistic function of relative species richness along a soil pH gradient in biome *b*. The minimum pH level for each species in each biome was reported by Azevedo *et al.* (2013b) (data available in appendix S2.4.2 of chapter 2 of this thesis).

Fourth, we determined the effect factor (MEF, mol $H^{-1}\cdot L$) as the marginal increase of the PNOF (dimensionless) following an increase in hydrogen ion concentration (C_j, mol $H\cdot L^{-1}$) at the receiving environment *j* location as

$$MEF_j = \frac{dPNOF_j}{dC_j} = PNOF^2 \cdot e^{\frac{\alpha_b-log_{10}C_j}{\beta_b}} \cdot \frac{1}{\beta_b \cdot C_j \cdot ln(10)} \tag{3.3}$$

where C_j is the hydrogen ion concentration determined as output of the PROFILE model and the biome-specific log-logistic coefficients α and β were determined with each receiving soil compartment *j* was allocated to its respective biome *b* using the map by Olson *et al.* (2001). For the (sub)tropical dry broadleaf and coniferous forests, for which regression coefficients were unavailable, we employed the coefficients for (sub)tropical moist broadleaf forest as they encompass fairly similar climate conditions according to the Köppen-Geiger classification (Schiel, 1985). The biome-specific coefficients are presented in appendix S3.1 of the Supporting Information.

3.2.5 Region-specific characterization factors

Since the specific source locations of the input and output processes compiled in the LCI phase are seldom known (Finnveden *et al.*, 2009), LCA practitioners often require coarser resolutions to assess the potential impacts of compiled emission inventories. We calculated CFs for larger spatial units (i.e., world, continent, and country) as the average of CFs of grids located within each unit. As a measure of the spatial variability within each of the three units, we calculated the spread in grid-specific CFs within each unit as

$$R = log_{10}\left(\frac{CF_{i,p}}{CF_{U,p}}\right) \tag{3.4}$$

where R is the ratio between grid-specific CF in grid *i* and CF_U is the CF of the larger spatial unit *U* (i.e., world, continent, or country) for pollutant *p.*

3.2.6 Significance of transboundary transport

To estimate the importance of emission impacts occurring to continents other than to that where the emission originated from, we calculated the intercontinental transboundary transport (CTT, %) as

$$CTT = 1 - \frac{CF_{U,p}}{CF_{i,p}} \tag{3.5}$$

where CTT is the fraction of emission impacts of grid *i* taking place in elsewhere continents and $CF_{U,p}$ is the continent-specific CF in which grid *i* in located in.

3.2.7 Contribution of fate and effect factors

The influence of the FFs, SFs, and EFs on the spatial variability of the CFs was evaluated for each emitting grid using a linear regression analysis. To attain that, we calculated grid-specific CFs whereby the variability was solely due to the atmospheric fate factor (thus, no soil sensitivity or effect factor influence) and due to the atmospheric and soil fate factors (thus, no effect factor influence). This exercise was done for the three pollutants separately.

3.3 Results

3.3.1 Characterization factors

Highest CFs were found at emission locations situated in central Asia, central Africa and Canada (Figure 3.1). CFs are largest for emission locations with dominant transport to areas with low buffering capabilities (indicated by high pH change) and a working point of the pH-PNOF relationship curve associated with a steep slope value.

The median CF of SO_2 (4.5 $m^2 \cdot yr \cdot kg^{-1}$) is higher than the median CF of NH_3 (4.3 $m^2 \cdot yr \cdot kg^{-1}$) and NO_x (2.1 $m^2 \cdot yr \cdot kg^{-1}$), Figure 3.1(d). CFs range over four (for NO_x), five (for SO_2) and six (for NH_3) orders of magnitude. The spatial variability of the CFs of a given pollutant is orders of magnitude larger than the variability between pollutants.

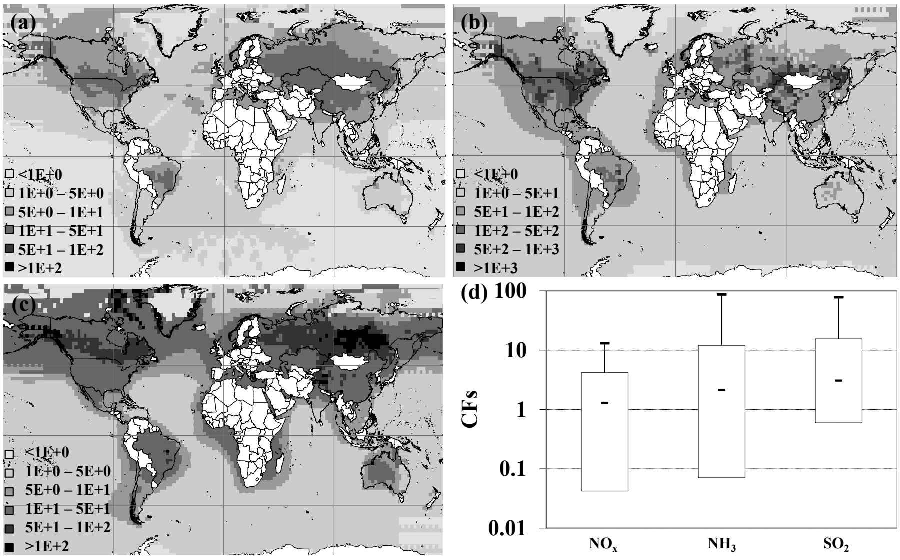

Figure 3.1 *Grid-specific characterization factors ($m^2 \cdot yr \cdot kg^{-1}$) for* ***(a)*** *$NO_x$,* ***(b)*** *$NH_3$ and* ***(c)*** *SO_2 emissions. Boxplot of CFs is shown in* ***(d)****.*

3.3.2 Region-specific characterization factors

Global, continental, and country averaged CFs are available in appendix S3.2. Figure 3.2 shows that respectively 41 – 54%, 4 – 12% and 3 – 10% of the grid-specific CFs within the global, continental, and country spatial resolutions, are more than one order of magnitude higher or lower compared to the specified coarser spatial resolution CFs.

3.3.3 Significance of intercontinental transboundary transport

Figure 3.3 shows the CTT occurring outside the continental scale for continental emissions of NO_x, NH_3, and SO_2. For example, depending on the emitted pollutant, between 60 and 70% of continental 2^ox2.5^o grids have less than 10% of their total potential impact associated with transboundary transport. On average, 15%, 12% and 13% of the NO_x, NH_3 and SO_2 impacts from continental emissions occur outside the continental scale, respectively. Grid-specific CTTs are shown in Figure S3.3.1.

3.3.4 Regression analysis

Table 3.1 presents the results of the regression analysis. Results showed an explained variance of less than 0.07 for $\sum FF$ towards CF. The explained variance of $\sum FF \cdot SF$ towards CF results is an explained variance between 0.95 and 0.97 with slopes of the linear regression that approximate 1. The stronger correlation between $\sum FF \cdot SF$ and CFs is also confirmed by the relatively low standard error and residual sum of squares of the regressions.

3.4 Discussion

3.4.1 Spatial variation

Relatively high CFs are obtained for emissions locations with depositions in areas with high SFs and EFs. Roy *et al.* (2012b) showed that highest sensitivity factors occurred in the Canadian shield region, the Scandinavian region, the Amazon basin, central Africa and parts of east and southeast Asia. EFs are highest in the “desert and xeric shrubland biome” and in the “tundra biome”. The soil sensitivity factor contributes most to spatial variability in the CFs, as shown by the regression analysis.

Application of the spatial explicit CFs in a full LCA would require regional life cycle emissions databases. Recently database providers such as ecoinvent (v3) (Godbold & Calosi, 2013) developed regional modules that cover different regions of the world and address the geographical locations of emission flows. Spatial explicit CFs still provide relevant information for situations when regional life cycle inventory is not or only partially available. CFs calculated at different level of aggregation (country, continent or world) with the associated information on spatial variability allows LCA practitioners to assess the uncertainty inherited from the lack of spatial information.

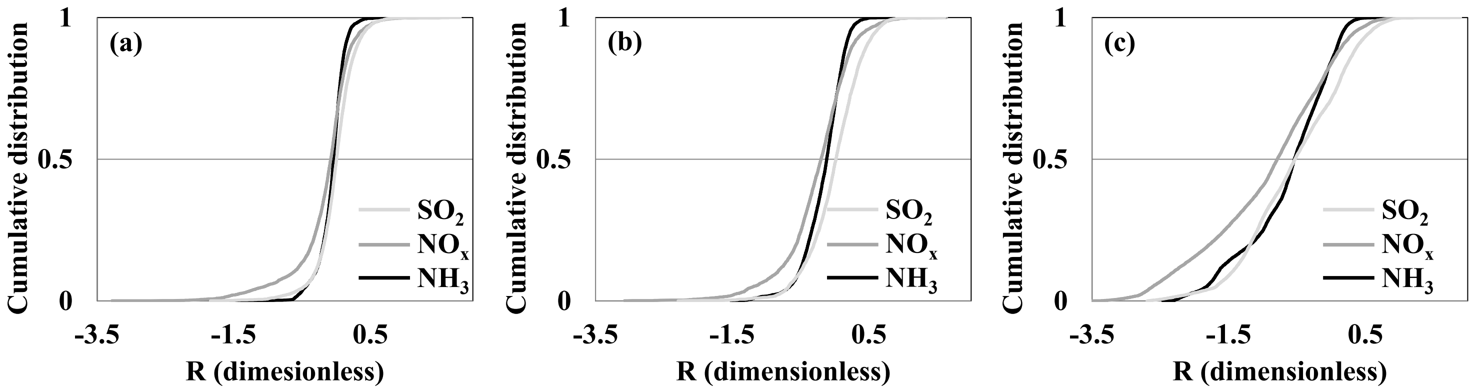

Figure 3.2 *Cumulative distribution of the ratio* $R = log_{10}\left(\frac{CF_{i,p}}{CF_{U,p}}\right)$ *between grid-specific and the **(a)** country, **(b)** continent, and **(c)** global CFs.*

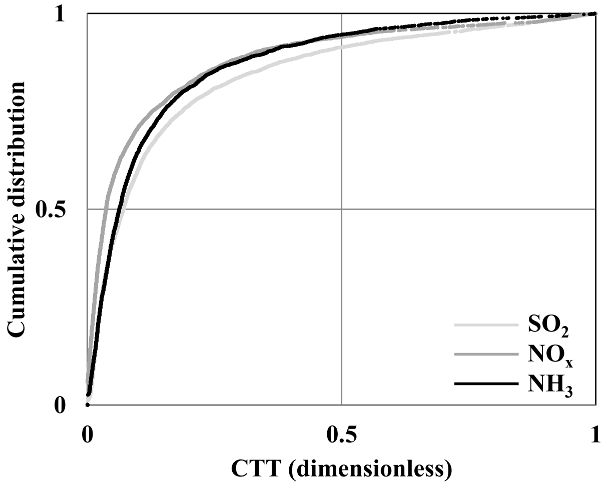

Figure 3.3 *Contribution of intercontinental transboundary transport* $CTT = 1 - \frac{CF_{U,p}}{CF_{i,p}}$ *to the grid-specific CF.*

Table 3.1 *Linear regression analysis of the spatial variability between characterization factors and* ***(a)*** *atmospheric fate and* ***(b)*** *atmospheric fate and soil sensitivity factors.*

Regression	R^2	Standard error	Residual sum of squares
(a) Atmospheric fate			
NO$_x$ log (CF) = 0.2 log (∑FF) + 1.9	0.00	0.63	3923
NH$_3$ log (CF) = -2.1 log (∑FF) - 16.4	0.07	0.88	8031
SO$_2$ log (CF) = 0.2 log (∑FF) + 2.7	0.00	0.73	5861
(b) Atmospheric fate and soil sensitivity			
NO$_x$ log (CF) = 1.0 log(∑FF×SF) + 3.7	0.96	0.12	140
NH$_3$ log (CF) = 1.0 log (∑FF×SF) + 3.8	0.97	0.16	255
SO$_2$ log (CF) = 1.0 log (∑FF×SF) + 3.9	0.94	0.17	324

3.4.2 Uncertainty

There are also assumptions in the modeling that can influence the CF results. First, deposition was considered evenly distributed within a 2°x2.5° grid, neglecting local factors favoring deposition (e.g. mountains) in certain regions within the grid. Without higher resolved global atmospheric models, this situation cannot be averted.

Second, terrestrial acidification can be caused via various cause-effect pathways, including nutrient depletion and an increase in soil solution H$^+$ concentration (or decrease of pH) and aluminum toxicity (Jeffries &

Ouimet, 2004). By using soil solution H^+ concentration as the soil sensitivity indicator, we evaluated the direct harm to the vegetation. The increase in soil solution H^+ concentration was chosen over the other types of indicators because it is recognized as a successful predictor of species richness and a primary indicator of soil acidity (Peppler-Lisbach & Kleyer, 2009, Whittaker, 1972). Furthermore, Roy *et al.* (2012b) showed that other soil sensitivity indicators, such as aluminum concentration or nutrient concentration (in the form of base cations), were more sensitive to soil input parameters uncertainties as compared to soil solution pH.

Third, biomes comprising soils that are inherently less acidic (e.g., deserts and mediterranean), encompass a PNOF at a pH level higher than other biomes (high α values, Table S3.1.1). This occurs because, in the past, the species which were able to subside in basic soils were favored while others perished (Azevedo *et al.*, 2013b). The opposite took place in acidic soils, e.g. temperate conifer and tropical moist forests, and tropical grasslands. This reflects in the sensitivity of species to pH declines (represented by the effect factor). In more alkaline soils, the increase in PNOF with pH declines is more pronounced than in soils where the species fraction reaches a reduction to 50% at acidic conditions.

Fourth, our approach based on marginal change, as used by many authors, may still raise concerns. Firstly, the quantification of a marginal change is still under discussion as several authors (Huijbregts *et al.*, 2000, Krewitt *et al.*, 2001, Potting *et al.*, 1998b) used a +10% variation, while others tried a combination of different values with a maximum of 50% (Seppälä *et al.*, 2006, van Zelm *et al.*, 2007). We deemed a 10% variation as satisfactory since Roy *et al.* (2012b) tested the variations of the receiving environment sensitivity factor over 100 randomly chosen receiving environments with increments of deposition of 1%, 5% and 10% and found a quasi-linear relation between the registered pH at 5% and 10% increment. Secondly, other approaches such as the *average* (Huijbregts *et al.*, 2011) or linear (Amores *et al.*, 2013, Gandhi *et al.*, 2010, Rosenbaum *et al.*, 2008) approaches could have been used instead. However, selection of any of these approaches should not modify significantly the obtained results since, on average, the effect factor equaled 1.9E-6, 1.3E-6 and $1.7E\text{-}6 \cdot 10^5$ mol $H^{-1} \cdot L$ for the marginal, average and linear approach, respectively.

Finally, missing model regression parameters impaired the effect assessment in Central America, India and the mountain regions of Asia. These territories were approximated with parameters from other environments. The lack of data for these regions hinders the accurate interpretation of the potential impacts.

3.4.3 Comparison with other studies

We compared our European CFs with the CFs from Goedkoop & Spriensma (2001) and van Zelm *et al.* (2007). Results are presented in Table 3.2. While our CFs are higher than the ones previously obtained, they are of similar orders of magnitude; which tend to make them acceptable. The elaborated differences below may explain the discrepancies in obtained results.

This study and the study of van Zelm *et al.* (2007) showed a similar relative importance of NO_x, NH_3, and SO_2 per unit emission. However, van Zelm *et al.* (2007) derived, systematically lower CFs. This may be explained by the fact that van Zelm *et al.* (2007) i) used the EUTREND (Beaufort *et al.*, 2011) atmospheric model, which does not include transboundary emission and related impacts outside of Europe (an average difference of 15%); ii) used the dynamic soil model SMART (Benner *et al.*, 2013), whose steady-state version showed a 25 to 65% difference with PROFILE when calculating critical loads (Nakamura *et al.*, 2011); iii) assessed changes in soil base saturation instead of H^+ concentration; iv) used a base saturation – PNOF dose-response curve that yielded a gentler slope than the H^+ concentration – PNOF dose-response, thus resulting in lower EFs in Europe (0.26 per base saturation comparatively to, on average, 1.9E-6 mol $H^{-1}\cdot L$); v) had EFs that equaled 0 for forest whose base saturation values were lower than 0.15 while our EFs were always greater than 0; and vi) limited their assessment of potential impacts to European forest ecosystems, unlike our assessment, which included numerous types of ecosystems; forests were shown to have one of the species – pH shallowest slopes

This study and that of Goedkoop & Spriensma (2001) resulted in similar (in terms of order of magnitude) absolute CFs for NO_x and NH_3 and differ significantly for SO_2 results. However, there exists several discrepancies between both studies: Goedkoop & Spriensma (2001) i) modeled the impacts for the Netherlands and extrapolated their EF results to Europe; ii) did not rely on atmospheric fate modelling, preferring a 10 mole marginal change to mapped deposition levels; iii) used the SMART model to evaluate changes in many soil properties, iv) assessed the potential impacts of both acidification and eutrophication instead of soil acidity changes; and v) assessed the potentially

Table 3.2 *Comparison of available endpoint CFs.*

	This study		**van Zelm *et al.* (2007)**		**Goedkoop & Spriensma (2001)**	
	CFs (m^2·yr·kg)	Contribution (%)	CFs (m^2·yr·kg)	Contribution (%)	CFs (m^2·yr·kg)	Contribution (%)
NO_x	9.8	11.4	0.4	15.6	5.7	25.6
NH_3	46.9	54.5	1.5	62.9	15.6	69.7
SO_2	29.4	34.1	0.5	21.5	1.0	4.66

disappeared fraction of species (PDF) for more than 900 Dutch plant species with the MOVE model (Latour & Reiling, 1993) contrarily to our biome approach.

3.4.4 Concluding remarks

This study determines spatially-explicit CFs for terrestrial acidification at the global scale. We showed the importance of including the potential impacts of intercontinental transboundary transport in CF calculations. Consequently, available LCIA methods underestimated the potential impacts of acidifying emissions. We revealed that spatial variability of a given pollutant is orders of magnitude larger than the variability between pollutants. Regardless of the remaining limitations, the proposed approach opens the door to evaluating the regional life cycle emissions of different products in a global economy.

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Chapter 4

Calcifying species sensitivity distributions for ocean acidification

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ABSTRACT

Increasing global CO_2 atmospheric levels have led to increasing ocean acidification, thereby enhancing dissolution of calcium carbonate of marine calcifying organisms. In this study, we gathered peer-reviewed experimental data on the effects of acidified seawater on the growth, reproduction, and mortality of calcifying species. The experimental data were used to derive species-specific half maximum effective concentrations, i.e. EC_{50}, and 10% maximum effective concentrations, EC_{10}, and, subsequently, we developed a probabilistic model of the cumulative affected fraction of species exposed to ocean pH stress, known as species sensitivity distributions (SSDs). Our results show that species growth is most affected by pH declines (where average of EC_{50} and EC_{10} were 7.53 and 7.93, respectively) than reproduction or mortality (where average EC_{50} and EC_{10} ranged from 7.45 to 7.74 and 7.46 to 7.65, respectively). The constructed SSDs were then applied to two climate change scenarios in order to estimate the change in the potential fraction of species affected (ΔPAF) by future ocean acidification. EC_{50}-based and EC_{10}-based ΔPAF varied from 4 to 6% and 8 to 33% in a low emission climate change scenario, respectively. In a high emission scenario, ΔPAF ranged from 12 to 13% (for EC_{50}-based effects) and from 19 to 70% (for EC_{10}-based effects). This study provides the first SSDs developed for ocean pH and an application of SSDs towards estimating the potential effects of global climate change on calcifying marine species assemblages.

4.1 Introduction

Rises in atmospheric carbon levels have led to increasing uptake of CO_2 by oceans (IPCC, 1990). This process, characterized by enhancement of dissolved CO_2 levels and the decrease in ocean pH, leads also to amplification of carbonate dissolution in oceans (Feely *et al.*, 2009). As calcifying species depend on highly saturated carbonate conditions in oceans in order to guarantee the building of their shells and skeletons (Secretariat of the Convention on Biological Diversity, 2009), carbonate dissolution following ocean acidification may pose a particular threat to these species.

Since the process of calcification is observed in a wide variety of taxa (such as phytoplankton, corals, and arthropods), denigrating effects of ocean acidification may go beyond the disruption of the various ecosystem services those species provide, including nursery for fish and protection against erosion and storms by corals, fisheries of urchins and invertebrates, and food provisioning for predators (Secretariat of the Convention on Biological

Diversity, 2009). Some important life processes may also suffer impairment, such as species growth or reproduction (Kroeker *et al.*, 2010).

Many laboratory experiments have assessed the effects of ocean acidification on individual species, which allowed for various meta-analyses of the effects of acidification on marine species, i.e. Chan & Connolly (2013), Kroeker *et al.* (2010), and Hendriks *et al.* (2010). Those studies have shown that acidification effects on marine species, particularly on the calcifying ones, are mainly detrimental (Kroeker *et al.*, 2010), although the responses of individual species are far from uniform (Hendriks *et al.*, 2010).

In environmental risk assessments, species-specific responses to a certain environmental stressor can be incorporated with species sensitivity distributions (SSDs). SSDs are commonly used in the estimation of effects of toxicants on species, such as metals or pesticides. They are particularly useful for (1) the estimation of the overall response (and the variability in responses) of an assemblage of species representing the species found in the environment and (2) the estimation of acceptable or “safe” levels of a stressor for the protection of the environment (Posthuma *et al.*, 2002). SSDs of the effects of marine species to increasing CO_2 exposure have been developed by de Vries *et al.* (2013). However, probabilistic models of a subsequent acidification effect of CO_2 level rises on ocean chemistry, namely pH declines, have not yet been developed for calcifying species, which are species that are particularly sensitive to the acidification of oceans (Kroeker *et al.*, 2010).

Here, we developed species sensitivity distributions (SSDs) based on three life processes (i.e. growth, reproduction, and mortality) and apply the SSDs to two global climate change scenarios of the Intergovernmental Panel on Climate Change, IPCC (2000). Growth, reproduction, and mortality are often indicators of the maintenance of species populations in the environment as they reflect the performance of species at important life processes (Schiel, 1985). Additionally, we assess if species potentially benefited from pH declines and if other important factors influence species responses, namely duration of experiments and water temperature levels.

4.2 Material and methods

4.2.1 Data inventory

We considered laboratory experiments on calcifying species conducted by 98 studies previously assembled by Kroeker *et al.* (2010) and Hendriks *et al.* (2010). We categorized the effect measured in each experiment into one of three response types, i.e. mortality, reproduction, or growth. Effects allocated to mortality include mortality and malformed or incomplete single cell organism growth. Effects allocated to reproduction include gamete abnormality, number of eggs, and fertilization success. Effects allocated to growth include growth or calcification rate, calcium content, and organism length. We excluded experiments whereby the taxonomic level of the tested organism was not species and experiments where the reported effect was related to a metabolic change in the organism and, thus, could not be allocated to neither of the three responses, e.g. O_2 productivity, photosynthetic rate or amount of rubisco.

We also recorded the duration and the temperature at which each experiment was conducted. When a pre-specified number of generations was employed by the study to determine the duration of the experiment, we employed the number of generations times the approximate life cycle of the species. For example, for the experiments conducted with *Emiliania huxleyi* by Langer *et al.* (2009), we assumed the life cycle of the organism as of one day.

For each experiment, we recorded the ocean pH to which species were exposed and the effect of the species. In experiments where CO_2 partial pressure (pCO_2) was reported instead of water pH, we converted pCO_2 to pH using the procedure described in appendix S4.1 of the Supporting Information. The empirical data on the pH condition and its effect on species were then employed in the derivation of SSDs for each experiment. We did not include empirical data of a specific experiment where the tested pH levels were above 8.35 or where the highest tested pH was below 7.95 as those conditions do not represent contemporary levels of ocean pH but past or future estimations of pH levels instead (Feely *et al.*, 2009).

4.2.2 Derivation of EC_{50} and EC_{10}

For each experiment, we first scaled the effect at each pH level between zero and one, where zero is the lowest and one is the highest relative effect reported for the tested species. Second, we fitted the empirical data to the logistic regression

$$Y_{t,s,e} = \frac{1}{1+10^{-\left(\frac{pH-EC50_{t,s,e}}{\beta_{t,s,e}}\right)}} \tag{4.1}$$

where $EC50_{t,s,e}$ is the pH leading to an effect on the species equivalent to 50% and $\beta_{t,s,e}$ is the slope of the logistic function for life process *t* (i.e., mortality, reproduction, and growth) of species *s* in experiment *e*. Third, we recorded which experiments indicated a denigrating effect of pH (i.e., $\beta_{t,s,e} < 0$, at a 95% confidence level), a beneficial effect (i.e., $\beta_{t,s,e} > 0$, at a 95% confidence level), or undetermined effect (i.e., $\beta_{t,s,e}$ not significantly different than zero or p value of the logistic regression above 0.05). For denigrating effects, we proceeded by calculating the pH leading to an effect of 10% in experiment *e* as

$$EC_{10_{t,s,e}} = -\beta_{t,s,e} \cdot log_{10}(9) + EC_{50_{t,s,e}} \qquad (4.2)$$

If multiple multiple $EC_{50_{t,s,e}}$ values were available for a particular life process of a species, the highest $EC_{50_{t,s,e}}$ was employed for the derivation of the $EC_{10_{t,s,e}}$ and of the PAF functions. This is a conservative approach as the effect on a species is given at the highest reported pH value.

4.2.3 Species sensitivity distributions

For each life process *t* and effect concentration *c* (i.e., EC_{50} and EC_{10}, hereafter defined as severe and subtle effects, respectively), the cumulative potentially affected fraction of species (PAF) was calculated as

$$PAF_{pH,t,c} = \frac{1}{\sqrt{2\pi\sigma_{t,c}}} e^{-\frac{(pH-\mu_{t,c})^2}{2\sigma_{t,c}^2}} \qquad (4.3)$$

where $\mu_{t,c}$ and $\sigma_{t,c}$ are the average and standard deviation of species-specific EC_{50} or EC_{10} value. We determined the statistical uncertainty around the PAF at each pH level using a Monte Carlo exercise (10,000 simulations). This was attained by first determining the uncertainty around μ and σ, which was executed following the procedure described by Roelofs *et al.* (2003). In this procedure, the uncertainty around the μ and σ coefficients is augmented for SSDs encompassing fewer species.

4.2.4 Influence of water temperature and experiment duration

For denigrating effects of pH declines, tested if the duration and the temperature at which experiments were conducted affected the $\boldsymbol{EC_{50_{t,s,e}}}$. This step was conducted for each of the three life processes as

$$\omega = \theta + \gamma_T + \gamma_D + \epsilon \qquad (4.4)$$

where ω is the estimated EC_{50} for a given life process, θ is the intercept, γ_T and γ_D are the coefficients for the temperature T and duration D factors, and ε is the residual of the multiple linear regression.

4.2.5 Climate change scenarios

Two climate change scenarios proposed by the Special Report on Emissions Scenarios, SRES (2000) were employed in order to estimate the fraction of species potentially affected by future ocean acidification. The scenarios B1 and A2 describe, respectively, low and high greenhouse gas emission scenarios and differing with respect to social-economic and technological developments expected in the future (IPCC, 2000). In addition to the decline of 0.1 pH unit which has already occurred since the industrial revolution (Orr *et al.*, 2005), Joos *et al.* (2011) project global average pH at the ocean's surface to be 7.95 and 7.8 by 2100 under the B1 and A2 climate change scenarios.

The change in PAF was calculated for each life process t and effect concentration c for both future scenarios F as

$$\Delta PAF_{F,t,c} = PAF_{F,t,c} - PAF_P \qquad (4.5)$$

where $PAF_{F,t,c}$ and PAF_P are the PAF as a function of future and present ocean pH levels, respectively.

4.3 Results

Ninety-eight studies testing the effects of ocean acidification on species mortality, reproduction, or growth were assembled by Kroeker *et al.* (2010) and Hendriks *et al.* (2010) and considered for our inventory of experiments. Thirty studies encompassed at least one experiment with 3 or more tested pH levels (i.e. the minimum necessary to fit a logistic regression described in equation 4.1) and organisms recorded at the species taxonomic level. A total of 174 experiments was tested for a logistic trend, of which 41 yielded a detrimental effect of pH decreases on species (i.e. negative relationship between pH and effect on species), Table 4.1. We also found a beneficial effect (positive relationship) of pH declines on the growth and reproduction of four species (Table S4.3.1).

The duration of experiments ranged from two hours to 60 days while ocean water temperatures ranged from 14 to 27ºC (Table 4.1). Despite the wide ranges of temperature and experiment duration, these two factors generally had no influence on EC_{50} results (Table 4.2). However, for mortality, temperature was negatively correlated with EC_{50} (p value = 0.044).

The experiment-specific logistic regressions yielded EC_{50} for fifteen different species (listed in Table S4.2.1). The organisms belonged to the Mollusca, Haptophyta, Cnidaria, Echinodermata and Arthropoda phyla. The SSDs for the three life processes based on EC_{50} and EC_{10} are shown in Figure 4.1. The arthropods *Acartia erythraea* and *A. steueri* were among the least sensitive to low pH levels while the mortality of hapophytes *Emiliania huxleyi* and *Calcidiscus leptoporus* were among the most pH-sensitive species. Molluscs (i.e. *Saccostrea glomerata*, *Crassostrea virginica*, and *Mytilus edulis*) comprised the organisms most sensitive for pH decreases with respect to growth responses.

The number of species available for the development of the SSDs varied across life processes. For growth, eleven species were available while, for reproduction, SSDs comprised of five species. The average sensitivity of species to growth effects was higher than for reproduction or mortality for severe effects (EC_{50}-based $\mu_{growth} > \mu_{mortality} = \mu_{reproduction,}$ Figure 4.1) and sutble effects (EC_{10}-based $\mu_{growth} > \mu_{reproduction} > \mu_{mortality}$). Additionally, we found a higher variability across mortality effects of species than for growth or reproduction (EC_{50} and EC_{10}-based $\sigma_{mortality} > \sigma_{reproduction} > \sigma_{growth}$).

In the low emission scenario, the increase in the PAF of subtle effects following a decrease in pH from 8.1 to 7.95 varied from 8% for mortality and 33% for growth (Figure 4.2). For severe effects, the same decrease in pH prompted an increase of 4% for growth to 6% for mortality in the PAF. In the high emission scenario, pH declines of 0.3 units prompted subtle effects ranging from 19% for mortality to 70% for growth and severe effects from 12% to reproduction to 14% for growth.

Table 4.1 *Logistic regression coefficients, i.e.* EC_{50} *and slope (95% confidence interval) for detrimental effects of pH decreases on species* ***(a)*** *growth,* ***(b)*** *reproduction, and* ***(c)*** *mortality. Temperature T and duration D of experiment is also shown.*

Species$^{\#}$	**EC$_{50}$**	**Slope β**	**R^2 / p value**	***T*** **(ºC)**	***D*** **(day)**
(a) Growth					
Hem_pul$^{E,¥}$	7.05 (6.74 to 7.36)	-0.76 (-7.53 to -0.40)	0.88 / 0.01	14	3
Ech_mat$^{E,¥}$	7.06 (6.92 to 7.2)	-0.78 (-1.32 to -0.55)	0.97 / <0.01	24	3
Sty_pis^{M}	7.40 (7.32 to 7.47)	-0.38 (-0.68 to -0.26)	0.98 / <0.01	27	20
Sac_glo$^{M,¥}$	7.48 (7.26 to 7.7)	-0.36 (-1.87 to -0.20)	0.97 / 0.01	18	2
Ocu_arb^{C}	7.56 (7.54 to 7.58)	-0.24 (-0.29 to -0.21)	1.00 / <0.01	25	60
Arg_irr^{M}	7.61 (7.43 to 7.79)	-0.46 (-1.71 to -0.26)	0.97 / 0.01	25	60
Cra_gig^{M}	7.66 (7.58 to 7.75)	-0.45 (-0.82 to -0.31)	0.61 / <0.01	20	0.1
Emi_hux$^{H,¥}$	7.72 (7.67 to 7.77)	-0.21 (-0.52 to -0.13)	1.00 / 0.02	20	12
Cal_lep^{H,¶}	7.74 (7.6 to 7.87)	-0.35 (-1.38 to -0.2)	0.98 / 0.01	20	10
Cra_vir^{M}	7.76 (7.6 to 7.91)	-0.36 (-1.92 to -0.2)	0.98 / 0.01	25	60
Myt_edi^{M}	7.76 (7.7 to 7.82)	-0.24 (-0.53 to -0.15)	0.66 / <0.01	20	0.1
(b) Reproduction					
Aca_ery^{A}	6.94 (6.74 to 7.14)	-0.18 (-0.18 to -0.18)	1.00 / <0.01	27	8
Aca_ste^{A}	7.29 (7.28 to 7.3)	-0.26 (-0.27 to -0.25)	1.00 / <0.01	27	6
Ech_mat^{E}	7.50 (7.40 to 7.6)	-0.48 (-0.75 to -0.35)	0.98 / <0.01	24	0.1
Hem_pul$^{E,¥}$	7.59 (7.47 to 7.72)	-0.45 (-1.26 to -0.27)	0.95 / <0.01	14	0.1
Sac_glo$^{M,¥}$	7.92 (7.87 to 7.96)	-0.11 (-1.78 to -0.06)	0.99 / <0.01	18	2

Species$^{\#}$	**EC$_{50}$**	**Slope β**	**R^{2} / p value**	***T* (ºC)**	***D* (day)**
(c) Mortality					
Tri_gra^{E}	6.78 (6.56 to 6.99)	-0.36 (-2.68 to -0.20)	0.96 / <0.01	26	4
Aca_ery^{A}	6.85 (6.84 to 6.85)	-0.26 (-0.26 to -0.26)	1.00 / <0.01	27	8
Cra_vir^{M}	7.49 (7.46 to 7.52)	-0.26 (-0.56 to -0.17)	1.00 / 0.01	24	20
Oph_fra^{E}	7.80 (7.71 to 7.89)	-0.02 (-0.11 to -0.01)	1.00 / <0.01	14	8
Emi_hux^{H}	7.85 (7.82 to 7.88)	-0.13 (-0.21 to -0.09)	1.00 / <0.01	19	12
Cal_lep^{H,¶}	7.98 (7.94 to 8.03)	-0.20 (-0.37 to -0.14)	0.99 / <0.01	20	10

$^{\#}$ Legend of abreviations of species names can be found in Table S4.2.1.

^{A}Arthropoda, ^{H}Haptophyta, ^{M}Mollusca, ^{E}Echinodermata, ^{C}Cnidaria

¶ Life cycle of organism assumed to be of 1 day

$^{¥}$Species with more than one available EC$_{50}$ result. The highest EC50 value was used and the others were discarded. These values are: (a) Growth: Ech_mat: 7.00; Emi_hux: 7.69 and 7.72; Hem_pul: 7.03; Sac_glo: 7.33, 7.35, 7.39, and 7.43 and (b) Reproduction: Ech_mat: 6.83, 6.97, 7.18, and 7.40; Hem_pul: 6.91, 7.22, and 7.39; Sac_glo: 7.66, 7.78, 7.82, and 7.90.

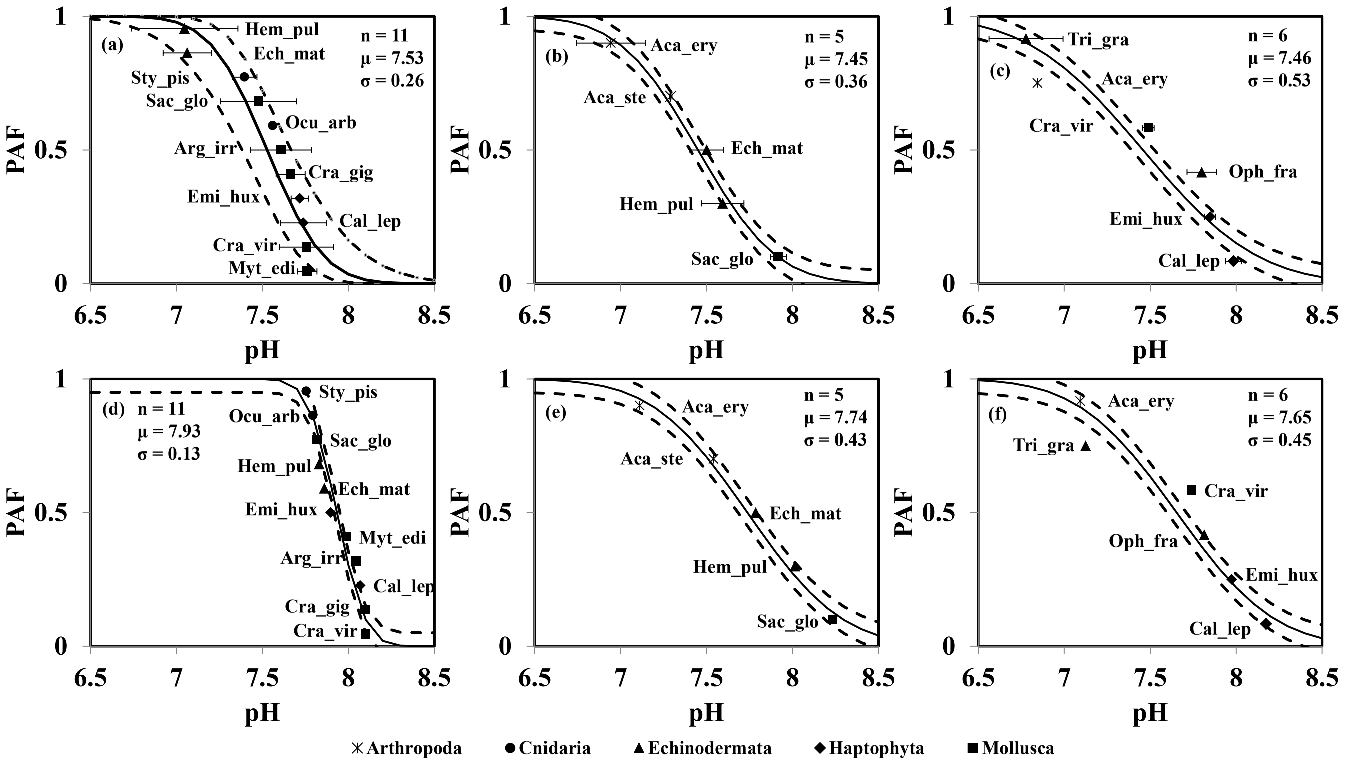

Figure 4.1 *Species sensitivity distributions (SSDs) of the potentially affected fraction (PAF, continuous line) based on* EC_{50} *values for* ***(a)*** *growth,* ***(b)*** *reproduction,* ***(c)*** *and mortality and based on based on* EC_{10} *values for* ***(d)*** *growth,* ***(e)*** *reproduction, and* ***(f)*** *mortality. Legend of abbreviations species can be found in Table S4.2.1. The error bars illustrate the 95% confidence intervals around the* EC_{50} *or* EC_{10} *of each species determined with the logistic regression. Dashed lines are the 5th and 95th percentile around the PAF.*

Table 4.2 *Results of the multiple linear regression of the influence of temperature (T) and duration (D) of experiments on* EC_{50} *for the three life processes. In the three regressions, the Shapiro-Wilk test for normality of residuals yielded non-significant results (p value > 0.05).*

	Coefficient (± S.E.)	**p value**	**Model sum of squares / R^2**
(a) Growth	.		0.089 / 0.13
Intercept	7.487		
T	-0.003 (0.025)	0.898	
D	0.004 (0.004)	0.342	
(a) Reproduction			0.351 / 0.670
Intercept	8.129		
T	-0.023 (0.038)	0.597	
D	-0.051 (0.061)	0.491	
(c) Mortality			1.141 / 0.823
Intercept	8.963		
T	-0.087 (0.026)	0.044	
D	0.037 (0.024)	0.216	

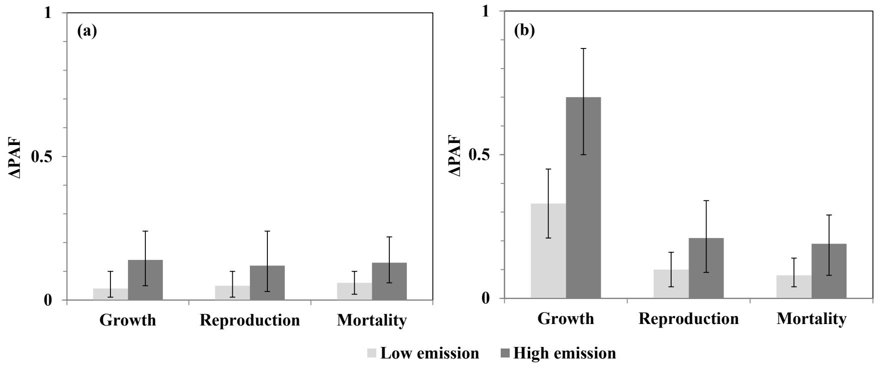

Figure 4.2 *The change in the potentially affected fraction (ΔPAF) in low and high greenhouse gas emission scenarios on* ***(a)*** *severe (i.e.,* EC_{50}*) and* ***(b)*** *subtle (i.e.* EC_{10}*) effects. Error bars are the 5th and the 95th percentile around ΔPAF.*

4.4 Discussion

In this work, we gathered data on ocean acidification experiments reported by peer-reviewed studies. In each experiment, the effect of pH decreases on species was allocated to three possible responses: growth, reproduction, and mortality of individual organisms. Species-specific EC_{50} data were employed in the construction of SSDs and we estimated the change in the PAF of calcifying species in two global climate change scenarios. Below, we discuss the main uncertainties of the analysis and interpret our results.

4.4.1 Uncertainties

We constructed SSDs based on EC_{50} and EC_{10} derived from experiments where detrimental effects of pH declines on calcifying species were confirmed. However, pH effects were not always detrimental to species since, for many experiments, we found no significant logistic function between pH declines and effects to life processes of species (Table S4.3.2). Ocasionally, pH declines prompted a beneficial effect on the growth and reproduction of species (Table S4.3.1). Although, in general, calcification may decrease under increasing acidic conditions, Wood *et al.* (2008) argued that echinoderms may counterweight such effects by altering other physiological processes (such as enhancing muscle wastage and, consequently, reducing their motility) so as to maintain high calcification rates.

In some cases, multiple EC_{50} results were obtained for individual species (i.e. total of four, Table 4.1). For *E. huxleyi*, for example, both benefiting and detrimental effects of pH declines were found. These discrepancies may be due to inherent differences between populations of species across experiments, e.g. Beaufort *et al.* (2011) or the metabolic plasticity of species exposed to ocean acidification (Godbold & Calosi, 2013, Wood *et al.*, 2008). However, discrepant EC_{50} results for one species may have resulted from the lack of standardization between the experiments with respect to their duration, temperature, salinity, etc., (de Vries *et al.*, 2013).

Nevertheless, with the exception of mortality responses, neither temperature nor duration of experiments appears to interact with pH on determining EC_{50} results. Interacting effects of temperature and acidity of oceans remain inconclusive since there are evidences of both antagonistic and synergistic effects of these two climate change related stressors (Benner *et al.*, 2013, Byrne *et al.*, 2009).

In the derivation of logistic regressions in each experiment, we only included the effects at pH levels below 8.35. The choice of discarding more alkaline conditions is based on the fact that marine waters rarely reach 8.35 (Takahashi & Sutherland, 2013). For the calculations of expected changes in the PAF from current to estimated pH scenarios, we assumed current pH levels of 8.1, which is the level of monthly averages of ocean pH reported by Takahashi & Sutherland (2013) at different world's locations.

The SSDs we developed do not take into account spatial variability or seasonal differences across species assemblages. However, such differences are known to occur. For example, while some of the species considered have a global distribution (e.g., *C. leptoporus*), while others have narrower distribution (e.g., *Oculina arbuscula*). Testing if the SSDs would differ depending on spatial or temporal patterns are beyond the scope of this study but, primarily, because acquiring enough EC_{50} data for different locations or seasons would be a limiting factor in the derivation of SSDs and would considerably decrease the confidence around PAF estimates.

4.4.2 Interpretation of results

Species growth is particularly affected by ocean acidification because changes in water chemistry directly influence the dissolution of calcium carbonate in extracellular tissue (Kroeker *et al.*, 2010). This pattern appears to be homogeneous across the species comprising the SSDs since the variability of species-specific EC_{50} for growth is considerably lower than for reproduction or mortality (Figure 4.1a-c). This effect has previously been documented for different species of *Acropora* and attributed to an energy-saving strategy whereby metabolic rates of coral larvae are suppressed and, consequently, survivorship remains unaffected under short term acidified seawater (Nakamura *et al.*, 2011).

In this study, we did not find any detrimental but a beneficial effect to the growth of arthropods (Table S4.3.1). Likewise, the reproduction and mortality of arthropods and the growth of the echinoderms were among the least affected by pH declines. This lack of sensitivity to acidified water may have been prompted by attributed to the presence of spikes in the calcareous exoskeleton of sea urchins (de Vries *et al.*, 2013) or the more extensive biogenic covering of some crustaceans, e.g. *Penaeus plebejus*, which can diminish the dissolution of $CaCO_3$ from their exoskeleton to seawater (Ries *et al.*, 2009). By contrast, molluscs such as *Mytilus edulis* comprise an exoskeleton that with a high content of highly soluble aragonite in their skeleton, which prompts their growth to be particularly affected by acidified ocean waters (Beesley *et al.*, 2008). The difference in chemical composition of the exoskeleton of mussels and crustaceans may have generated the apparent discrepancies between EC_{50} results between the two species groups.

Mortality of hapophytes (i.e. *E. huxleyi* and *C. leptoporus*) was affected by pH declines and yet we also found beneficial effects to the growth of *E. huxleyi* (Table S4.3.1). This seeming contradiction has been reported before (Beaufort *et al.*, 2011) and it may be a consequence of, one hand, their increasing photosynthetic activity, which would promote the organism’s development, and, on the other hand, their decreasing calcification (Engel *et al.*, 2005).

4.4.3 Concluding remarks

Our study shows how species-specific responses of calcifying species to pH declines can be implemented in environmental risk assessments. Our results show that responses not only vary across taxa but also across life processes of species. The employment of SSDs for ocean acidification may be useful to assessments of ocean acidification risks since they allow for the identification of particularly sensitive groups of calcifying species and the estimation of inter-species variability responses to pH declines. Additionally, we show how SSDs can be used for the estimation of the potential fraction of the species assemblage affected in different global climate change scenarios.

ACKNOWLEDGMENTS

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Chapter 5

Species richness – phosphorus relationships for lakes and streams worldwide

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MODIFICATIONS FROM PUBLISHED VERSION

1- Figures 5.2, 5.3, and S5.2.1 are shown in grey scale, not in color;
2- The projection of the map of Figure 5.2 is Gall-Peters not Aitoff;
3- Table S5.2.2 shows total phosphorus concentration ranges of species per habitat not ranges in across all regions.

ABSTRACT

We investigated the patterns of autotrophic and heterotrophic relative species richness along a total phosphorus (TP) concentration gradient on a global scale. The relative species richness – TP relationships were calculated separately for four different regions [(sub)tropical, xeric, temperate, and cold] and two types of water bodies (lakes and streams). Using data from peer-reviewed articles reporting the occurrence of freshwater species at specific TP concentrations, we determined the species richness along a TP gradient. Using log-logistic regressions, we then estimated the TP concentration at which the potential decrease of relative species richness (RSR) equals 0.5 and the slope at which the decrease occurs (β). The RSR is given as the ratio of species richness to maximized species richness along a TP gradient. The RSR of streams generally decreased more rapidly than that of lakes with increasing P, as illustrated by the steeper slope of the log-logistic functions for streams ($\beta_{\text{lakes}} < \beta_{\text{streams}}$). Although there was no consistent trend between autotrophs and heterotrophs in the different regions, we found that the TP concentration at which the RSR equals 0.5 was lower in cold regions (0.04 – 0.22 mg P/L) than in warmer regions (0.28 – 1.29 mg P/L). The log-logistic relationships between RSR and TP concentration vary considerably among regions of the world, between freshwater types (lakes and streams) and between species groups (autotrophs and heterotrophs). This variability may be attributed to differences between the two freshwater types in respect to their species groups and evolutionary patterns, nutrient demand, biogeochemical and hydrologic processes. We were not able to derive log-logistic regressions for all combinations of freshwater type or species type and region [e.g., (sub)tropical lakes]. For other areas, our results can be used to assess the potential impact of phosphorus eutrophication on freshwater biota.

5.1 Introduction

The intensification of agriculture, industrialization, and urbanization has led to increasing fluxes of phosphorus (P) worldwide (Liu & Wang, 2007). In freshwater systems, this nutrient is regarded as the main factor driving primary productivity (Schindler, 1974). In addition to increases in biomass, changes in autotrophic and heterotrophic species richness associated with P concentrations have been reported (McIntyre *et al.*, 2007, Penning *et al.*, 2008, Rumes *et al.*, 2011). For example, high crustacean species richness was found in eutrophic (sub)tropical lakes, while richness of macrophytes in temperate lakes (Rumes *et al.*, 2011) was maximized at intermediate total-phosphorus levels (Penning *et al.*, 2008). The rate of nutrient recycling in tropical streams has also been linked to fish species richness (McIntyre *et al.*, 2007), suggesting that total-phosphorus levels and faunal richness are strongly correlated.

Because aquatic eutrophication is currently considered one of the strongest threats to water quality and stream biodiversity worldwide (Björklund *et al.*, 2009, Vörösmarty *et al.*, 2010), it is important to identify the freshwater types and regions whose biotic communities are most affected by P imbalances. Many studies have focused on the effects of increasing P in one or more specific water bodies, species, or regions (Dodson *et al.*, 2000, Smith *et al.*, 2007, Struijs *et al.*, 2011b). However, to our knowledge, no study has outlined the effects of different P concentrations on relative species richness on a global scale. Understanding how decrease in relative species richness due to P increases may occur in different regions of the world and in different freshwater types is essential for the ecological assessment of eutrophication impacts.

The goal of this study was to compare the relationships between P concentration and the relative species richness of autotrophs and heterotrophs in lakes and streams in different regions of the world. We first performed an inventory of peer-reviewed observational field data, which yielded a large number of studies worldwide. We then derived concentration-response relationships based on this dataset. Given that the cause-effect relationships obtained from nutrient-addition experiments may reflect only small spatial and temporal coverage, observations from surveys make it possible to derive concentration-response relationships for other areas or periods.

Concentration-response relationships are commonly applied in toxicology and can be used to compare the sensitivity of different species groups to changes in the concentration of the stressor of interest. They can also be directly coupled with existing biogeochemical models of the fate of P in inland waters, such as those used in Global NEWS (Harrison *et al.*, 2005, van Drecht *et al.*, 2005), the Millennium Ecosystem Assessment (van Drecht *et al.*, 2009b), life cycle impact assessments (Helmes *et al.*, 2012), or estimation of past or expected ecological risk of stressors (Fedorenkova *et al.*, 2012, Leuven *et al.*, 2011), to ultimately determine the relationships between environmental stressors and relative species richness in freshwater systems.

5.2 Material and methods

5.2.1 Species richness – total P relationships

We chose total P (TP) as our stressor of interest because it is the recommended P fraction for water quality monitoring (Lewis *et al.*, 2011) and is commonly reported in water-quality studies. Based on observational studies of species occurrence, we calculated the relative species richness of autotrophs and heterotrophs along a TP gradient. Subsequently, we derived log-logistic regressions of the relative species richness in lakes and streams in (sub)tropical, temperate, cold, and xeric regions. Each step is described in detail below, and the complete framework is illustrated in Figure 5.1.

We computed the overall species richness (SR) as the number of species reported in 0.1 $\log_{10}$-transformed concentration intervals (C_i, mg P/L) for streams and lakes in different regions as

$$SR_{i,t,h,g} = \sum_{log_{10}C_i} O_{t,h,g} \tag{5.1}$$

where $O_{t,h,g}$ is the occurrence of a given species in species group *g* (autotrophs or heterotrophs) at nutrient concentration C_i in freshwater type *t* (stream or lake) in region *h*. O is one if the species is reported to be present and zero if the species is not present.

We identified the concentration of TP at which $SR_{i,t,h,g}$ is at its maximum (SR_{max}). This approach has been applied by Struijs *et al.* (2011b) for genus-level macroinvertebrate richness in Dutch streams as a function of TP-induced stress and by Azevedo *et al.* (2013b) for vascular-plant species richness in biomes as a function of low-pH stress. The TP concentration at which SR equals SR_{max} is hereafter referred to as the optimum TP concentration, C_{opt}. To compare SR – TP concentration relationships between autotrophs and heterotrophs, between lakes and streams, and among regions, we transformed SR into a relative species richness measure as

$$eRSR_{i,t,h,g} = \frac{SR_{i,t,h,g}}{SR_{max_{i,t,h,g}}}, for\ C_i \geq Copt \tag{5.2}$$

following Azevedo *et al.* (2013b) and Struijs *et al.* (2011b), where eRSR is the empirical relative species richness (eRSR) of species in group g at concentration C_i in freshwater type t in region h. At C_{opt}, eRSR is one. Conversely, an eRSR of zero represents the complete absence of species. At C_i values lower than C_{opt}, we consider that SR is no longer affected by the excess P (Struijs *et al.*, 2011b). Thus, eRSR is here described only for C_i values larger than C_{opt}. It is important to note that species richness – TP relationships are typical bell-shaped curves, with species richness also decreasing at limiting nutrient levels (Penning *et al.*, 2008, Struijs *et al.*, 2011b). In this study, we were interested in how individual species' tolerance to high TP levels might influence species richness – TP relationships. Therefore, we limited the analysis to the eutrophic side of the curve, i.e. at C_i greater than C_{opt} (Struijs *et al.*, 2011b).

Next, we used a log-logistic model of the calculated RSR (cRSR) by fitting it to eRSR as

$$cRSR_{i,t,h,g} = \frac{1}{1+e^{-\left(\frac{\log_{10} C_i - \alpha_{t,h,g}}{\beta_{t,h,g}}\right)}}, for\ C_i \geq C_{opt} \qquad (5.3)$$

The coefficient α indicates the $\log_{10}$ TP concentration at which relative species richness is 0.5, and β indicates the slope of the log-logistic regression. We fitted both cRSR coefficients (α and β) using logistic regression in SAS 9.2. The sample size for the log-logistic regression is given by the number of $SR_{i,t,h,g}$ data points (at 0.1 $\log_{10}$ TP-concentration intervals). We considered a log-logistic model to fail to fit the empirical data if it had a p value > 0.05, a β coefficient non-different from zero at a 95% confidence level, or an α coefficient outside the concentration range at which eRSR data were available (between C_{opt} and the maximum observed TP level). To test for potential sampling bias resulting from different sampling effort across regions, we tested whether the number of species or the number of studies was correlated with our results for C_{opt}, α, or β.

5.2.2 Sensitivity analysis

We conducted a sensitivity analysis to investigate how our regressions might vary if smaller spatial units were used. For this analysis, we used the methodology described above, but at smaller spatial levels of detail: freshwater ecoregions [delineated by Abell *et al.* (2008)], regions within individual realms, and individual studies in our data inventory. Azevedo *et al.* (2013b) have suggested employing a sensitivity analysis based on repeating the procedure using smaller spatial-aggregation levels to identify differences in ecoregions within terrestrial biomes.

We repeated the sensitivity analysis to determine how our results would change if we distinguished among specific taxonomic groups within the autotrophic and heterotrophic groups. Autotrophs were divided into cyanobacteria, silicon-based algae, non-silicon-based algae, and macrophytes, while heterotrophs were divided into fish and invertebrates.

COLLECTION AND MANAGEMENT OF DATA

1- Keyword selection of peer-reviewed articles (see keyword combination in Box 1, appendix 1) and selected studies in Table S5.1.1

2- Allocation of studies into their respective habitat and freshwater type (Fig. 5.2)

3- Allocation of species to its respective species group and trophic group (see taxonomic classification method in Table S5.2.1)

4- Standardization of species occurence to presence /absence data

5- Determining the total P (TP) concentration range of occurence of each species (Table S5.2.3)

RESPONSE CURVES

6- Calculation of the species richness (SR) in each species group and freshwater type (Equation 5.1)

7- Identification of optimal concentration (C_{opt}) based on maximized species richness (SR_{max})

8- Calculation of the empirical relative species richness (eRSR) in each species group and freshwater (Equation 5.2)

9- Calculation of calculated RSR (cRSR) per species group and freshwater type (Equation 5.3). Results are shown in Table 5.1.

Figure 5.1 *Description of the steps taken for acquisition of data and derivation of response curves.*

5.2.3 Collection and management of data

To acquire data about the TP-concentration ranges at which specific aquatic species were reported to be present, we selected peer-reviewed articles using a combination of relevant keywords in *Web of Science* (lake, freshwater, phosphorus, etc.). The specific keyword combinations can be found in Appendix S5.1 in the Supporting Information. We included only articles that reported the locations of their field surveys and that recorded TP concentrations and species occurrences at the same sampling location and time. We also included species records from the *Limnodata Neerlandica* database (STOWA, 2010), which includes invertebrate-occurrence data and water-quality measurements for inland waters in the Netherlands. We did not consider brackish or inland saline waters or anthropogenic ecosystems, such as fish ponds or wastewater-treatment plants.

We grouped ponds and reservoirs with freshwater lakes and springs, rivers, and creeks with streams. Wetlands were excluded from this study. Furthermore, based on the geographical location of each study, we assigned each freshwater system to a biogeographical region: (sub)tropical, temperate, cold, or xeric. This division was based on the major freshwater habitat types (MHT) of the world, recently developed by Abell and colleagues of the FEOW project (Freshwater ecoregions of the world, http://www.feow.org). We combined the regions designated as temperate coastal rivers, temperate floodplain rivers and wetlands, and temperate upland rivers into one temperate region. Likewise, we combined (sub)tropical coastal rivers, (sub)tropical floodplain rivers and wetlands and (sub)tropical upland rivers into one (sub)tropical region. Although the MHT map delineated by the FEOW includes many freshwater types, such as temperate floodplain rivers and wetlands, we used the freshwater-type classification given by each inventoried study. Montane and polar freshwater systems were combined and referred to as the cold region. Studies located in the MHT classes Oceanic Islands, Large Lakes, and Large River Deltas (such as studies located in the Great Lakes and Lake Peipsi regions, the Paraná River basin, and the Azores Islands) were assigned to the closest adjacent habitat.

We selected species belonging to the following groups: autotrophs (comprising cyanobacteria, silicon-based algae, non-silicon-based algae, and macrophytes) and heterotrophs (comprising aquatic invertebrates and fish). We used the Integrated Taxonomic Information System database (www.itis.gov) for the nomenclature of invertebrates and fish, the PlantList (www.theplantlist.org) for macrophytes, and the AlgaeBase (www.algaebase.org) for cyanobacteria, silicon-based algae, and non-silicon-based algae (for details on the allocation of each organism, Table S5.2.1). We included records at taxonomic levels lower than species (i.e., variety and subspecies) when they were available, considering them as species-level records. Next, we standardized the different reporting methods in each study (e.g., biomass and abundance) into an occurrence/non-occurrence dataset for each species. For example, if biomass was greater than zero, then we considered the species as occurring.

We then derived the TP-concentration range at which each species occurred in streams or lakes within each water body in each region following the method described by Azevedo *et al.* (2013b). Each concentration range represents the tolerance of an individual species to TP levels in a given freshwater type and region. Outside of these concentration boundaries, the species was considered absent. The range of occurrence (minimum and maximum concentration values) was calculated using one of the following procedures, in order of preference: (1) the lognormal variation distribution of 90% of the sample (Slob, 1994), (2) the minimum – maximum reported concentration range, or (3) the mean value alone. Finally, we considered the overall range of occurrence of each species to be represented by the lowest minimum and highest maximum concentrations obtained for that species in a given freshwater type in a given region. Species whose final minimum- and maximum-concentration values were equal were excluded from the dataset because this condition does not represent a true concentration range found in the environment.

5.2.4 Data set

Approximately 6800 studies were found using the keyword combinations, and 186 of these studies were applicable (see list of studies in Table S5.1.1). Most studies did not fulfill all the requirements of this data inventory, such as identifying organisms at the species level, sampling either lake or stream freshwater systems, and providing spatially explicit, field-observation data on TP concentrations.

Many studies (142) represented North American and European freshwater systems (Figure 5.2). The number of studies conducted in lakes and streams was 155 and 35, respectively (Table S5.1.1). The inventory included 2294 unique species, with 1318 and 1596 species-occurrence – TP-concentration records for autotrophs and heterotrophs, respectively (see Table S5.2.2 for specific species ranges). We found no data for autotrophs in

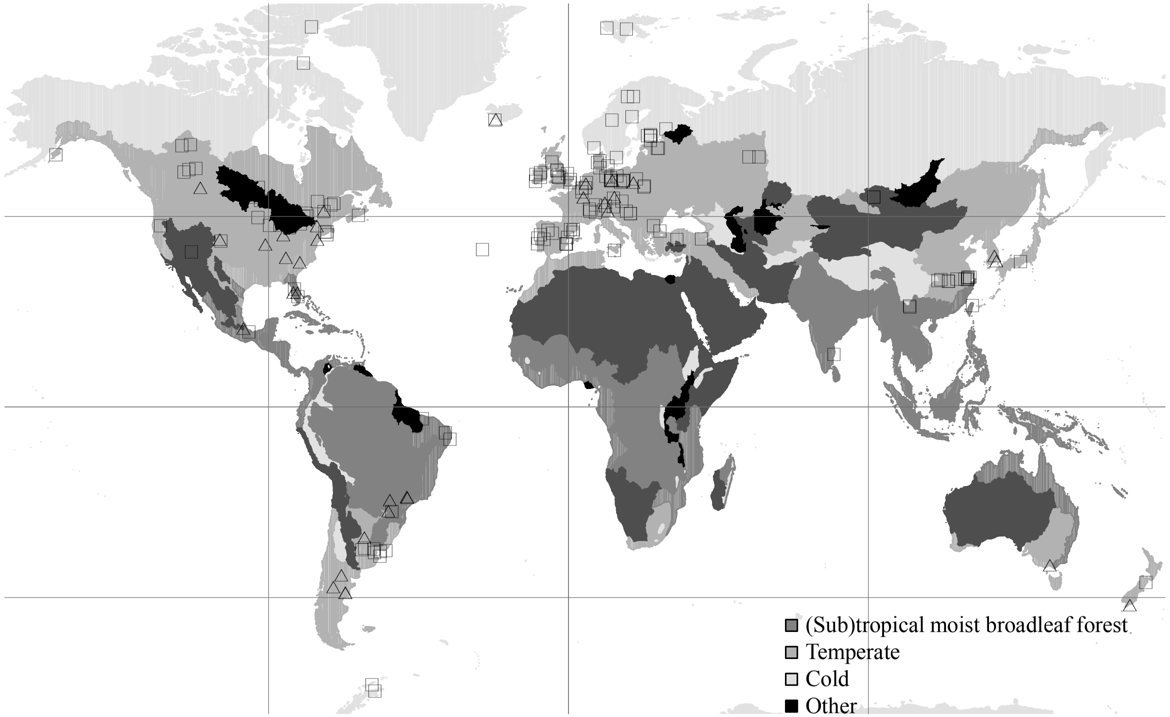

Figure 5.2 *World map with the location of the freshwater bodies used in this study allocated to four regions. The studies within "Other" areas (11), which represent large freshwater bodies and oceanic islands, were allocated to their closest region. Squares (155) and triangles (35) represent lakes and streams, respectively.*

cold-region streams or for autotrophs and heterotrophs in xeric-region streams.

5.3 Results

We were able to derive log-logistic functions for eight of the thirteen combinations of species group (autotrophs and heterotrophs), freshwater type (lakes and streams), and region for which eRSR data were available (Figure 5.3). The number of available species in each combination varied considerably, from 45 autotrophic species in xeric lakes to 835 heterotrophic species in temperate streams (Table 5.1). Figure S5.2.1 shows the scatter-plots of species richness vs. TP concentration that were used to define C_{opt} and to calculate eRSR.

The TP concentration at which species richness is maximized, C_{opt}, was lowest in cold-region lakes (0.02 to 0.03 mg P/L, Table 5.1). C_{opt} was generally higher in streams (0.07 to 0.20 mg P/L) than in lakes (0.02 to 0.10 mg P/L). We found no clear distinction between the C_{opt} values of heterotrophs and autotrophs across freshwater types and regions.

The log-transformed TP concentration at which RSR equals 0.5, represented by α, was highest in temperate streams (for both autotrophs and heterotrophs) and in xeric lakes (for autotrophs) (10^{α} = 1.0 to 1.3 mg P/L, Table 5.1). α was lowest for heterotrophs in cold-region lakes (10^{α} = 0.04 mg P/L).

The sensitivity of species to increasing nutrient levels is represented by the slope of the log-logistic function, β (the higher the β, the steeper the function). Heterotrophic RSR was systematically more sensitive to increases in P compared to autotrophic relative species richness, except in temperate streams. Autotrophs in temperate and cold lakes were the least sensitive to TP increases (β = -0.53 to -0.63).

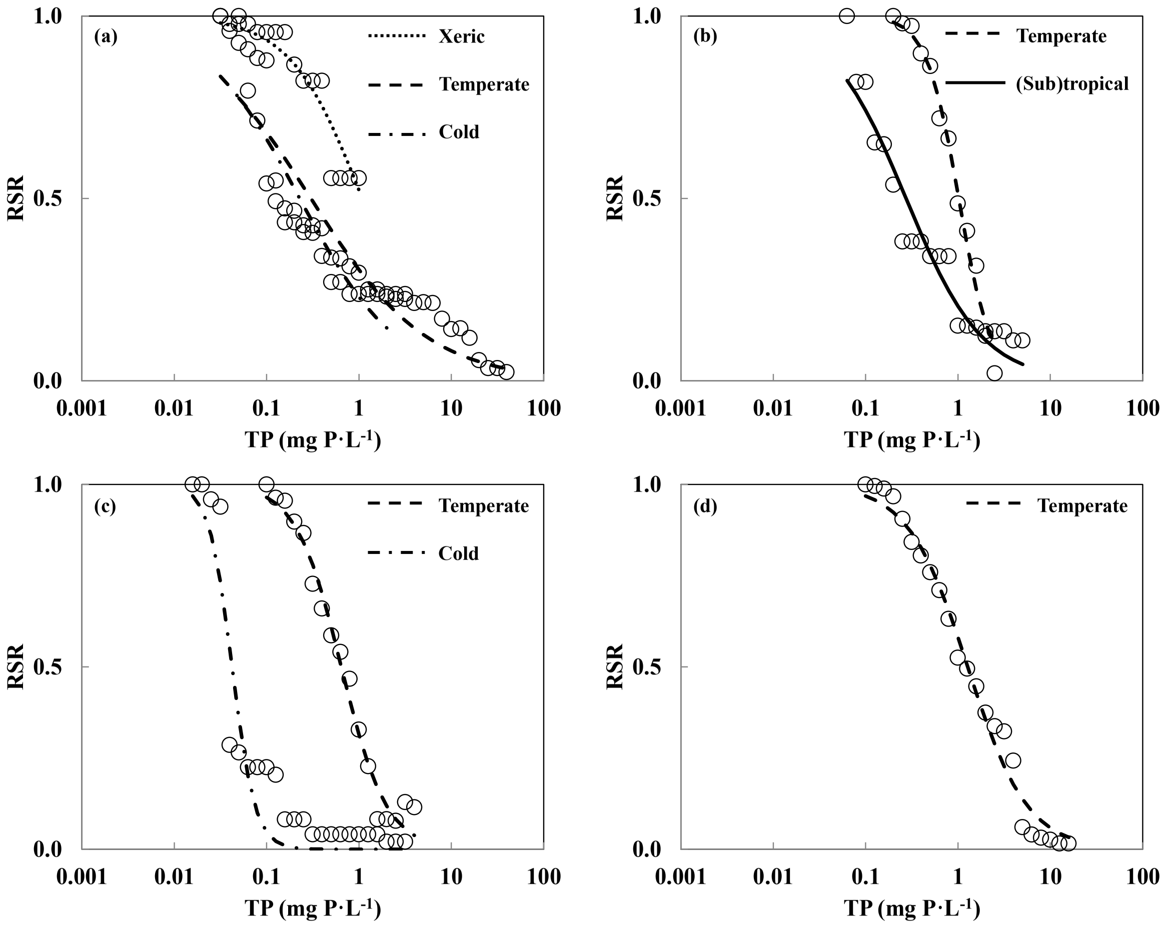

Figure 5.3 *Empirical (eRSR, circles) and the calculated (cRSR, lines) relative species richness of autotrophs along a total phosphorus (TP) gradient in lakes **(a)** and in streams **(b)** and of heterotrophs in lakes **(c)** and in streams **(d)**. Log-logistic coefficients used in the cRSR functions are shown in Table 5.1.*

Table 5.1 *Number of studies, surveyed range of TP (mg P/L), number of species (SR_{max}), optimum TP level in habitat, C_{opt} (C_{opt} across ecoregions in brackets), relative species richness (RSR) coefficients α and β and 95% confidence intervals (in brackets), $R^{2¥}$ (p value in brackets) of log-logistic regressions for two organism groups, in two freshwater types, and four world's regions.*

	Studies	**Surveyed range**	**Species**	$\mathbf{SR_{max}}$	$\mathbf{C_{opt}}$	**α *(95% CI)***	**β *(95% CI)***	$\mathbf{R^{2¥}}$ **/ p value**
(a) Lake autotrophs								
Cold	10	0.002 to 3.155	163	122	0.03 (0.005 to 0.03)	-0.64 (-0.76 to -0.52)	-0.53 (-0.67 to -0.40)	0.88 / < 0.001
Temperate	74	0.001 to 41.970	614	459	0.05 (0.002 to 0.32)	-0.52 (-0.66 to -0.38)	-0.63 (-0.78 to -0.48)	0.88 / 0.001
Xeric	2	0.009 to 1.180	45	45	0.03 (0.03 to 0.03)	0.03 (-0.07 to 0.14)	-0.39 (-0.50 to -0.28)	0.91 / 0.001
(Sub)tropical[#]	7	0.003 to 35.000	95	42	15.85 (0.001 to 15.85)	1.58 (0.98 to 2.18)	-0.19 (-0.78 to 0.39)	0.72 / 0.013
(b) Lake heterotrophs								
Cold	14	0.002 to 3.155	54	49	0.02 (0.003 to 0.02)	-1.37 (-1.43 to -1.31)	-0.12 (-0.18 to -0.07)	0.92 / 0.001
Temperate	61	0.001 to 4.070	682	488	0.10 (0.003 to 3.2)	-0.19 (-0.23 to -0.15)	-0.24 (-0.281 to -0.21)	0.98 / 0.001
Xeric	1	0.385 to 4.124	4	4	0.63[¶]	No successful fit with the log-logistic regression		
(Sub)tropical[#]	4	0.001 to 0.220	9	7	0.04 (0.005 to 0.04)	-0.82 (-0.86 to -0.78)	-0.03 (-0.07 to 0.01)	0.92 / 0.001
(c) Stream autotrophs								
Temperate	11	0.001 to 2.625	182	146	0.20 (0.001 to 0.50)	0.01 (-0.02 to 0.04)	-0.17 (-0.20 to -0.15)	0.99 / 0.001
(Sub)tropical	6	0.001 to 5.088	203	199	0.07 (0.001 to 0.08)	-0.56 (-0.64 to -0.48)	-0.41 (-0.50 to -0.33)	0.94 / 0.001

	Studies	Surveyed range	Species	**SR_{max}**	**C_{opt}**	**α *(95% CI)***	**β *(95% CI)***	**$R^{2¥}$ / p value**
(d) Stream heterotrophs								
Cold	1	0.010 to 0.044	2	2	0.02[¶]	No successful fit with the log-logistic regression		
Temperate	16	0.007 to 17.000	835	697	0.10 (0.01 to 0.40)	0.11 (0.06 to 0.15)	-0.32 (-0.36 to -0.29)	0.99 / 0.001
(Sub)tropical[#]	3	0.052 to 1.225	9	8	0.40 (0.1 to 0.40)	0.13 (-0.02 to 0.29)	-0.15 (-0.29 to -0.01)	0.85 / 0.001

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10^{α} coefficient was outside the TP concentration range of relative species richness (defined by C_{opt} to upper boundary of surveyed TP concentration)

[¶] Minimum and maximum range of C_{opt} based on one ecoregion only

[¥] $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{Corrected\,Total}}$, as defined by Schabenberger & Pierce (2001)

To analyze the robustness of our results, we compared how the choice of spatial scale would affect the log-logistic regression coefficients by aggregating the dataset into realms, ecoregions, and individual studies. We found that there may be high spatial variability across spatial units within a region (Appendix S5.3). However, the variability of the coefficients obtained for spatial aggregation at the level of regions was within the range of results obtained for these additional levels of aggregation.

The three phytoplankton groups showed similar sensitivity to TP changes within lakes in the same region (Table S5.3.5). The results for cyanobacteria species were not different for similar freshwater types across regions (Tables S5.3.5 and S5.3.6). On the other hand, phytoplankton species of temperate lakes (cyanobacteria, silicon-based and non-silicon-based algae) are less sensitive to TP changes than macrophytes (Table S5.3.5). However, invertebrates in cold-region lakes were more sensitive to TP changes than invertebrates in temperate lakes (Table S5.3.7). The overall heterotrophic group also showed greater sensitivity in cold-region lakes than in temperate lakes (Table 5.1). In the temperate region, the level of P at which heterotrophic lake species maintained 50% of their richness was similar to that obtained for invertebrates but higher than that obtained for fish (Table S5.3.7).

We were not able to derive log-logistic regressions for all smaller spatial units and specific taxonomic groups. For example, although there were nine ecoregions within the temperate region, we were able to derive regressions for stream autotrophs in only four of these ecoregions (i.e., Central & Western Europe, Northeast US & Southeast Canada Atlantic Drainages, Southeastern Korean Peninsula, and Upper Mississippi, Table S5.3.2). Likewise, no data were available for macrophytes in (sub)tropical streams; therefore, this species group was not evaluated.

5.4 Discussion

We derived the concentration-response relationships between TP and the RSR of autotrophic and heterotrophic species in two freshwater types (lakes and streams) in temperate, (sub)tropical, xeric, and cold regions. Below, we explore the main uncertainties of our study and interpret our results.

5.4.1 Uncertainties

First, the optimum concentration (C_{opt}) reported here corresponds to the maximal species richness found within an observed TP-concentration gradient. Thus, we assume that the RSR – TP patterns we report are valid for TP levels above but not below C_{opt}. This concentration does not necessarily correspond to minimally disturbed, "baseline" conditions. Nonetheless, the calculated C_{opt} values are within the range of target values established by the European Union and the United States Environmental Protection Agency, which range from 0.01 to 0.15 mg P/L (European Commission, 2000, Smith *et al.*, 2003). The species used in the regression above C_{opt} may have been more represented by high-TP-tolerant algae and less by species that are typically present at low nutrient levels. In fact, many species in our inventory were present at TP conditions below C_{opt} (Table S5.2.3), suggesting that these species may also be adapted to survive at low TP levels.

Second, in our study, the response of organisms to stress was estimated based on phosphorus levels alone because this nutrient is considered the primary limiting nutrient in freshwater systems (Carpenter *et al.*, 1998, Schindler, 1974). We did not consider the influence of other stressors, although these can also influence freshwater species. For example, nitrogen has been reported to influence primary productivity as much as phosphorus, and co-limitation has also been reported to drive eutrophication (Elser *et al.*, 2007). Lower light availability due to increasing turbidity or growth of macrophytes may hinder the influence of P (Le Bagousse-Pinguet *et al.*, 2012). Likewise, grazing pressure, oxygen availability, chlorophyll concentration, substrate texture, stream width or area, and lake depth have been reported as factors to explain the variability in species-richness responses to P (Amarasinghe & Welcomme, 2002, Friberg *et al.*, 2010, Huszar *et al.*, 2006).

In addition to abiotic stressors, the nutrient demands of planktivores or higher-order consumers may vary widely (Hall, 2009). These differences are frequently addressed by biomanipulation experiments (Carpenter *et al.*, 2001). Although the present study did not account for each species' position in the food chain, we distinguished organisms according to their primary nutrition pathways (i.e., their ability or inability to perform photosynthesis).

Third, the type or number of species representing each species group (autotrophs and heterotrophs) may depend on the research focus. For example, diatoms are commonly used for water-quality monitoring, but the Dutch water-quality database we employed (STOWA, 2010) focuses on macroinvertebrates. In cold- and temperate-region lakes, the number of invertebrate species was more than three times the number of fish species (Table S5.3.7). One outcome of the high number of invertebrates is that the

TP level at which 50% of the species are maintained for the overall heterotrophic group was similar to that for invertebrates but not to that for fish. Although taxa differ in their tolerance to high P levels (Caputo *et al.*, 2008), we did not account for these differences in this study. Our results should therefore be interpreted at the level of the overall autotrophic and heterotrophic species groups but not at lower taxonomic levels.

Fourth, due to the strong research effort in Western Europe and in eastern North America, we found numerous studies in the temperate region (Figure 5.2). This prompted the number of species employed to derive the RSR – TP functions in temperate systems to be higher than elsewhere. However, neither the number of studies nor the number of species used to derive our regressions influenced the results we obtained for C_{opt}, α, or β (appendix 4). In any case, the sensitivity analysis showed that there may be strong variability among areas within a specific region. For example, while the 10^{α} and β coefficients for temperate lake autotrophs were 0.30 and -0.63 mg P/L, respectively, individual studies yielded 10^{α} values ranging from 0.02 to 4.07 and β values ranging from -0.53 to -0.01 (Table S5.3.1). The choice of spatial units into which localities are aggregated to derive log-logistic regressions (e.g., regions, ecoregions, or individual studies) remains under discussion. For example, Azevedo *et al.* (2013b) derived regressions at the biome level of spatial detail, while Struijs *et al.* (2011b) and Amarasinghe & Welcomme (2002) defined their species-richness patterns per country and per continent, respectively.

Fifth, we gathered data on TP concentration ranges at which freshwater species were present. In conditions outside this surveyed range, it is uncertain whether the species truly becomes absent because of life-threatening concentration levels. In contrast to controlled experimental studies, field-based observational studies like those surveyed here provide less certainty as to the exact boundaries between tolerable and intolerable stressor conditions (Struijs *et al.*, 2011b). Therefore, we cannot confirm factual species disappearance since the calculations of species richness are not based on verified species loss but on first-encounter species occurrence. Ultimately, there may be an underestimation of relative species richness estimations which are based on first-encounter analysis as opposed to confirmed species loss due to intolerable TP levels. This concern has been recently defined as ‘dark diversity’ (Pärtel *et al.*, 2011) and it is commonly under scrutiny when the stressor of interest is the potential loss of species caused by damage to the species living space as such (He & Hubbell, 2011). In observational studies such as ours, the issue caused by unconfirmed species loss may be alleviated by thorough monitoring of species occurrence and by coverage of a wide TP-concentration gradient, up to highly eutrophic levels.

Finally, to compare the potential impact of phosphorus across regions with evident differences in species richness [e.g., cold vs. (sub)tropical freshwater systems], we employed a relative measure of relative species richness. Despite our effort to gather data from the literature, we were not able to successfully estimate the RSR in regions for which very few or no data were found, such as xeric-region streams and (sub)tropical lakes.

This species-occurrence/non-occurrence approach simplifies an effect type previously described in a continuous manner (e.g., biomass or abundance) into a simpler binary dataset (presence and absence). This standardization has the advantage of combining the different ways in which effects have been reported by different studies. While abundance is more commonly reported for species that are visible to the naked eye, other organisms are more frequently reported as present or absent in a given freshwater body.

5.4.2 Interpretation

Optimum TP

Our results show that the optimum TP concentrations are generally higher in streams than in lakes. This finding can be attributed to distinct biotic nutrient demands in the two freshwater types. First, because lakes require lower P levels than streams to reach the same net primary-productivity rate (Smith *et al.*, 1999), the optimum TP can be reached at lower concentrations in lakes than in streams. This pattern was observed across all autotrophic groups (cyanobacteria, silicon-based and non-silicon-based algae, and macrophytes) in the temperate region. Second, while nutrient surpluses in lakes are quickly reduced by widespread, fast-growing algae (Carpenter *et al.*, 1998, Doi, 2009), nutrient recycling in streams, especially those of lower size orders or with strong tree shading, depends primarily on the speed at which heterotrophs assimilate organic matter (Merritt *et al.*, 1984, Vannote *et al.*, 1980).

Another reason for the higher optimum TP levels in streams compared to lakes is the differences in hydrological patterns that influence nutrient removal from the water column. Once nutrients are deposited in the sediment layer via the sinking of soil, animal fecal pellets or algae, they can be either transported back into the water column or immobilized in the sediment for long periods (Holtan *et al.*, 1988). In streams, strong water currents enhance sediment uplift, favoring the maintenance of high TP levels in the water column (Bahnwart *et al.*, 1998). In addition, the short residence times of water in streams, especially lower-order streams, may decrease phytoplankton exposure to nutrients hence hinder autotrophic growth (Vannote *et al.*, 1980). Conversely, lakes, especially cold ones (Carpenter *et al.*, 1999), may be subjected to thermal stratification for many months, confining nutrients to the surface layer, where net primary productivity and nutrient recycling prevails, and hindering the vertical uplift of nutrient-rich sediments (Tylmann *et al.*, 2012).

Phosphorus loads are lower overall in the cold region than in the temperate and (sub)tropical regions due to lesser anthropogenic nutrient release in cold regions, e.g., agricultural runoff (Harrison *et al.*, 2010). Smaller decomposition rates in colder regions may also decrease nutrient release into water bodies. It is therefore likely that most species in cold regions are adapted to low nutrient concentrations. Because we were not able to derive regressions for both species groups in warmer regions [(sub)tropical and xeric], it is unclear how the climatic gradient represented by the four regions may influence C_{opt} across the two species groups.

Regression coefficients

Geological and evolutionary processes in freshwater systems will determine how tolerant the biotic community is to a given stressor. As a result, species in nutrient-rich environments will be more adapted to high nutrient levels than those unused to such conditions (Bontje *et al.*, 2011, Köhler, 1994). In this study, we found that the freshwater systems that could maintain half of the relative species richness at higher TP levels were also those with high optimum TP levels, C_{opt}. Nonetheless, this trend does not imply that organisms with high tolerance to elevated phosphorus levels are also less sensitive to changing levels of this nutrient.

Heterotrophs have higher P demands than autotrophs because autotrophs have higher N:P and C:P ratios (Elser *et al.*, 2000). Hence, heterotrophs are expected to be more affected by P surpluses than autotrophs (and more sensitive to changing P levels). In our study, however, this hypothesis was confirmed in temperate and cold-region lakes but not in temperate streams (Table 5.1). Here, we propose three explanations for the lower sensitivity of autotrophs in lakes compared to streams based on the difference in light availability and photosynthetic rates between the two freshwater types. This analysis is verified once phytoplankton species (cyanobacteria, silicon-based and non-silicon-based algae) are separated from macrophytes in the autotrophic group in temperate lakes. First, the increased production of N-rich protein and RNA by small organisms with high growth rates suggests that the biological demand for N may surpass that for P (Elser *et al.*, 1996). The lesser effect of P on autotrophs in lakes compared to streams may be due to more intense autochthonous phytoplankton activity in lakes than in streams (Doi, 2009). Second, the lower sensitivity of autotrophic richness to P changes can be attributed to the insensitivity of cyanobacteria to low-oxygen and high-P conditions (Downing *et al.*, 2001). Many cyanobacteria, including toxic groups (e.g., *Aphanizomenon*), compensate for their light demand in light-abundant lacustrine systems and for their N demand via N fixation; ultimately, P supplementation allows them to overcome their primary growth limitations (Camargo & Alonso, 2006b). Third, macrophytes help to maintain algal diversity under increasingly eutrophic conditions by impeding the fast-growing, light-favored phytoplankton that prevail in eutrophic lakes (Le Bagousse-Pinguet *et al.*, 2012). Given that the proportion of macrophytes within the autotrophic group was considerably higher in temperate lakes than in streams, the buffering effects of increasing P may be more intense in lakes compared to streams in the temperate region.

The sensitivity of organisms could be compared across lakes and streams only in the temperate region. We found that heterotrophic species were less sensitive to TP changes in streams than in lakes. This difference may be due to the high dispersal ability of heterotrophs in lakes, generating stronger similarity between species assemblages and thus lower β-diversity in lakes compared to streams (Hof *et al.*, 2008). If lakes contain more similar species assemblages, which are expected to react in a more similar way following stress exposure, then relative species richness will change more rapidly in lakes than in streams because streams encompass more dissimilar species.

The comparison across regions was hindered by the scarcity of data for (sub)tropical lakes and xeric streams. In addition, the influence of P on primary productivity is less apparent in (sub)tropical lakes than in temperate lakes (Huszar *et al.*, 2006), which may explain why we were not able to derive a log-logistic regression for this ecosystem. Huznar *et al.* (2006) and Abell *et al.* (2012) have suggested that nitrogen may drive primary production more than P does in (sub)tropical lakes because higher temperatures enhance nitrogen losses, particularly through denitrification, and P transport to water bodies due to weathering (Abell *et al.*, 2012).

Relevance of research and application of results

Global-scale assessments are available for the influence of P on net primary productivity in freshwater systems (Elser *et al.*, 2007). However, changes in species richness due to increasing P concentrations have previously been assessed in studies focusing on a specific freshwater type or covering a smaller area, e.g., Struijs *et al.* (2011b) and Friberg *et al.* (2010). The results of the present study show that the patterns of relative species richness along a TP-concentration gradient can be described using logistic regressions.

We identified patterns in the RSR along a TP-concentration gradient for two species groups (autotrophs and heterotrophs), in two freshwater types (lakes and streams), and in four regions [(sub)tropical, xeric, temperate, and cold]. We found that lakes generally, but not always, have lower optimal TP levels and that their species assemblages are less sensitive to TP changes than those in streams. Furthermore, autotrophs and heterotrophs in cold regions have lower optimal concentrations compared to those in other regions. The regressions can be used to describe the potential decrease in relative species richness in a quantitative manner, although it is important to note that factual causal relationships between species losses and P increases are not tackled in this study. In combination with biogeochemical models of the fate of nutrients, this procedure can assist in estimating the ultimate effects of stressors on species richness maintenance (Struijs *et al.*, 2011a, van Zelm *et al.*, 2007, Verbrugge *et al.*, 2012).

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Chapter 6

Assessing the importance of spatial variability versus model choices in life cycle impact assessment – the case of freshwater eutrophication in Europe

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MODIFICATIONS FROM PUBLISHED VERSION

1- TOC/Abstract Art is not included;
2- Description of the calculation of normalization scores (sub header 6.2.5) is included.
3- The projection of the map of Figures S6.2.2, S6.2.3, S6.3.2, and S6.3.3 is Gall-Peters not Plate Carée;
4- Figures S6.2.2, S6.2.3, S6.3.2, and S6.3.3 are shown in grey scale, not in color;
5- Results of the assumption tests of the analysis of variance shown in legend of Table S6.3.4 not as individual figures.

ABSTRACT

In Life Cycle Impact Assessment (LCIA) both spatial variability and model choices may be influential. In the case of the effect model, the effect factors differ with respect to their assumption of linear/non-linear responses to increases in environmental stressor levels, and whether or not they account for the current stressor levels in the environment. Here, we derived spatially-explicit characterization factors of phosphorus emissions causing eutrophication based on three different effect models (depicted by marginal, linear, and average effect factors) and two freshwater types (lakes and streams) and we performed an analysis of variance (ANOVA) to investigate how the selection of the effect models and the freshwater types influence the impacts of phosphorus emissions to freshwater on heterotrophic species. We found that 56% of the variability of ecological impacts per unit of phosphorus emission was explained, primarily, by the difference between freshwater types and, to a lesser extent, by the difference between effect models. The remaining variability was attributed to the spatial variation between river basins, mainly due to the variability in fate factors. Our study demonstrates the particular importance of accounting for spatial variability and model choices in LCIA.

6.1 Introduction

Life cycle impact assessment (LCIA) links an anthropogenic activity related to the life cycle of a product, service, or technology with its impact on the environment. As the impact may depend on site-specific characteristics, e.g. climate or sensitivity of resident species, spatially-differentiated methodologies for LCIA are now being developed for different categories of pollutants, nutrients, and resources (Hanafiah *et al.*, 2011, Núñez *et al.*, 2013, Saad *et al.*, 2011, Sala *et al.*, 2011, Struijs *et al.*, 2011a).

Spatial specificity is an important step in LCIA because it accounts for different regional responses to an anthropogenic activity. For example, Saad *et al.* (2011) found that groundwater recharge capacity varied eight-fold across different Canadian ecozones. Furthermore, not only are there differences across landscapes, but similar landscapes may also comprise compartments with differentiated sensitivity to stressors. For example, streams and lakes located in temperate regions comprise different food web structures and, consequently, their trophic level thresholds differ considerably (Doi, 2009, Smith *et al.*, 1999).

A spatially-explicit LCIA framework describes the environmental impact of an emission of a given pollutant on the ecosystem with characterization factors (CFs) as

$$CF_{w,i} = \sum_j FF_{i\to w,j} \cdot EF_{w,j} \qquad (6.1)$$

where $CF_{w,i}$ is the characterization factor for the pollutant emitted from region i to compartment w, $FF_{i\to w,j}$ is the fate factor (in days) describing the residence time of the pollutant in the environment transported from region i to compartment w in region j, and EF_j is the effect factor (in $m^{-3}\cdot kg$) describing the environmental impact (the fraction of potentially non-occurring or the disappeared fraction of species) following an increase of the pollutant concentration in compartment w in region j. The compartments included in the model can be numerous; here, we focus on freshwater lakes and streams.

Three different effect factor (EF) models are suggested for LCA (Huijbregts *et al.*, 2011, Rosenbaum *et al.*, 2008, Van de Meent & Huijbregts, 2005). The EF models differ with respect to the assumption of linearity/non-linearity of responses and data input requirements. The marginal effect factor model (MEF) estimates a small change of the impact of an emission due to a small change in the environmental concentration of a stressor. The rationale for the MEF is that the impact caused by an emission from an individual product system has only a small share in the overall impact on the environment (Van de Meent & Huijbregts, 2005). The linear effect factor model (LEF), primarily used if the ambient concentration of the pollutant is unknown, describes the change from a preferred state (a target state, with "zero" effect), where the concentration of the pollutant is zero, to the concentration where the effect is 50% of the maximum (Rosenbaum *et al.*, 2008). The average effect factor model (AEF) was recently proposed as an alternative to the MEF (Huijbregts *et al.*, 2011), reflecting the average distance between the current state and the preferred state of the environment.

Up to now, the influence of spatial variability versus effect model choices on characterization factors has not been investigated.

The goal of our study was twofold. First, we derived spatially-explicit endpoint CFs for phosphorus (P) emissions to freshwater by employing three effect models coupled with an existing model of the transport of phosphorus in freshwaters (Helmes *et al.*, 2012) on the Europe scale. A spatially-explicit impact assessment of the impact of phosphorus emissions is crucial given that anthropogenic P flows in the lithosphere over the last decades (Bouwman *et al.*, 2009, Cordell, 2010) and effects on species diversity are spatially-dependent (Penning *et al.*, 2008, Rumes *et al.*, 2011). Second, we assess how spatial variability and model choices affect CFs by comparing (1) spatial variability between river basins, (2) differences in impacts to two freshwater types (i.e. lakes and streams), and (3) differences between effect factor models. The term stream is hereafter used to denote flowing freshwaters, including rivers and streams.

6.2 Material and methods

6.2.1 Fate factors

We employed a grid-based model of the fate of P from its emitting location i to its receiving downstream grids j developed by Helmes *et al.* (2012) as partial fate factors $FF_{i \rightarrow w,j}$ (resolution: 0.5º x 0.5°). The fate factors describe the removal rates of P due to water advection, P retention, and water use in downstream grids j. In order to estimate the residence time of P in each freshwater type w (i.e. lake or stream), we included the volume fraction of freshwater type w in j. In each grid, the sum of the volume fractions of lakes and streams was equal to one. In cases where a single grid cell's freshwater volume was entirely lake or stream, the CF for the type with a zero volume fraction was also zero (n = 121, a total of 1789). These zero valued CFs were excluded from further analysis.

6.2.2 Effect factors

The three effect models are described by effect factors $EF_{w,j}$ for freshwater type w in receiving grid j (kg $P^{-1} \cdot m^3$) and they are based on log-logistic relationships between the potentially not occurring fraction (PNOF, dimensionless) of heterotrophic species and total P (TP) concentration ($C_{w,j}$, kg $P \cdot m^{-3}$). The PNOF – TP relationships were determined using data on the highest concentration of TP where a species was observed in field surveys in temperate regions (Azevedo *et al.*, 2013a), see details in appendix S6.1 of the

Supporting Information. The three model types chosen cover the range of effect approaches available to and meaningful in LCA.

The first effect factor, MEF (Van de Meent & Huijbregts, 2005), represents the marginal increase in PNOF due to a marginal increase in TP concentration $C_{w,j}$ and it is described as

$$MEF_{w,j} = \frac{\partial PNOF_{w,j}}{\partial C_{w,j}} = PNOF_{w,j} \cdot \left(1 - PNOF_{w,j}\right) \frac{1}{C_{w,j} \cdot \beta_w \cdot \ln(10)} \qquad (6.2)$$

where β_w is the slope of the PNOF – TP function in freshwater *w*.

The second effect factor, LEF, represents the linear change in PNOF due to an increase from $C_{w,j} = 0$ *to a* $C_{w,j}$ *where* PNOF in *w* in grid *j* is 0.5 (10^{α_w}, equation 6.3). It is commonly used in the derivation of effect factors for toxicants (Gandhi *et al.*, 2010, Rosenbaum *et al.*, 2008), for effect models employing with multiple endpoints (Amores *et al.*, 2013), or when stressor levels in the environment are unknown. It is described as

$$LEF_{w,j} = LEF_w = \frac{\Delta PNOF_{0.5}}{\Delta C_{w,j}} = \frac{0.5}{10^{\alpha_w}} \qquad (6.3)$$

The third effect factor, AEF, represents the average change in PNOF due to an increase from a "zero effect" ($C_{w,j} = 0$) to a monitored TP concentration $C_{w,j}$ (Huijbregts *et al.*, 2011). It is described as

$$AEF_{w,j} = \frac{\Delta PNOF_{w,j}}{\Delta C_{w,j}} = \frac{PNOF_{w,j}}{C_{w,j}} \qquad (6.4)$$

For the calculation of MEF and AEF, the environmental concentrations ($C_{w,j}$) were obtained from the water quality monitoring database of the European Environment Agency, EEA (2013b). We then calculated the annual mean TP concentration of lake and stream monitoring stations within each grid *j* (appendix S6.2).

6.2.3 Characterization factors

Grid-specific CFs are described as

$$CF_{w,i} = \sum_j FF_{i \to w,j} \cdot EF_{w,j} \qquad (6.5)$$

where $C_{w,i}$ (day·kg P^{-1}·m^3) is the characterization factor of emitting grid *i* for freshwater type *w*.

Using the centroid of each emitting grid i, we recorded in which river basin each grid was and then calculated characterization factors for each European river basin r and freshwater type w ($C_{w,r}$) as the mean of grid-specific CFs ($C_{w,i}$) within each basin. The river basins (total of 91) were mapped by the EEA (2012).

6.2.4 Influence of model choices

River basin characterization factors ($C_{w,r}$) were used as the experimental unit for an analysis of variance (ANOVA) as the fate of P transport emitted to grid i determines the CF of i but also influences the CF of grids downstream of i. By employing river basin instead of grid CFs, we avoid the interdependence of CFs between grids because P is not transported across but only within basins.

First, we tested to what extent the effect model and the freshwater type influenced river basin CFs with a completely randomized design ANOVA as

$$log_{10}CF_{w,r} = \mu + M_m + W_w + MW_{m,w} + \varepsilon \tag{6.6}$$

where μ is the intercept, M represents the main effect of method type (m = LEF, MEF, or AEF); W represents the main effect of freshwater type w; MW represents the interaction between method and freshwater type; and ε is the residual, which represents the spatial variability across river basins CFs. $CF_{w,r}$ was $\log_{10}$ transformed prior to the analysis to fulfill the assumptions of normality of residuals and homogeneity of variance of factors M and W (Table S6.3.4, appendix S6.3).

Second, in order to isolate the spatial variability across river basin CFs ($CF_{w,r}$) due to the fate and effect factors, we calculated river basin CFs whereby the variability was solely due to the residence time of P in each freshwater (thus, no effect factor influence) and due to the sensitivity of species to P increases (thus, no fate factor influence). This exercise was done six times, i.e. for the three effect factor models and two freshwater type combinations (see appendix S6.4 for calculation procedure).

6.2.5 Normalization scores

Normalization scores (NS, m^3) were calculated for each river basin r as

$$NS_{m,w,r} = CF_{m,w,r} \cdot \left[E_{S,r} + A_r \cdot f_{soil\rightarrow water} \cdot \left(E_{M,i} + E_{F,i}\right)\right] \tag{6.7}$$

where $CF_{m,w,r}$ is the characterization factor (day·kg^{-1}·m^{3}) for river basin r and freshwater w based on method m, A_r is the area (ha) of river basin r, $f_{soil \rightarrow water}$ is the fraction of phosphorus emitted to soil by manure and mineral fertilizer applications and that reaches the freshwater compartment, and E_S, E_M, and E_F (kg·ha^{-1}·day^{-1}) are the emissions for individual grid cell i of phosphorus from wastewater treatment plants, manure, and mineral fertilizers to water within river basin r, respectively.

$CF_{m,w,r}$ are reported in Table S6.3.1, A_r were calculated using the river basin map delineated by the EEA (2013b), and $f_{soil \rightarrow water}$ was estimated to be 0.1 (Bouwman *et al.*, 2009). Emission data for individual wastewater treatment plant (WTP) were reported by the EEA (2013a). For point sources (i.e., E_S), emissions were reported for individual WTP within a river basin r (kg·day^{-1}); WTPs within each basin were then summed to obtain E_S and it is assumed that there are no unreported WTP by the EEA (2013a). For nonpoint sources (i.e., E_M and E_F), emissions reported for individual grid cells i (resolution 0.5° x 0.5°) by Potter *et al.* (2011) were averaged per river basin.

6.3 Results

6.3.1 Characterization factors

The concentration of TP at which the PNOF is 0.5 (10^{α}, Figure 6.1) was lower for lakes than for streams by a factor of 1.8 ($10^{\alpha,lake} = 3.99 \cdot 10^{-4}$ kg P·m^{-3} and $10^{\alpha,stream} = 7.41 \cdot 10^{-4}$ kg P·m^{-3}). Additionally, the sensitivity of species to changes in TP levels (β coefficient) was higher in lakes than in streams ($\beta_{lakes} < \beta_{stream}$). Likewise, reported TP levels were generally higher in streams (Figure 6.2), with uppermost levels found in streams in Greece and throughout Germany and Poland (Figure S6.2.3b). High TP levels in lakes were found in Great Britain, Belgium, the Netherlands, and western Germany (Figure S6.2.3a) and the lowest TP levels were reported in the highlands of Scotland and in the Alps in both freshwater types.

The range of concentration-dependent effect factors (MEF and AEF) across grids was relatively similar for lakes (varying from zero to 1775 kg P^{-1}·m^{3}, Figure 6.2a) and for streams (varying from zero to 1235 kg P^{-1}·m^{3}, Figure 6.2b). EFs were observed at TP levels of $4.0 \cdot 10^{-5}$ kg P·m^{-3} to $7.3 \cdot 10^{-5}$ kg P·m^{-3} in lakes and $7.0 \cdot 10^{-6}$ kg P·m^{-3} to $1.4 \cdot 10^{-5}$ kg P·m^{-3} in streams. Grid-specific CFs were generally higher in lakes (Figures S6.3.1) compared to streams (Figure S6.3.2), especially in Ireland, the Baltic countries, Denmark, and northern Italy.

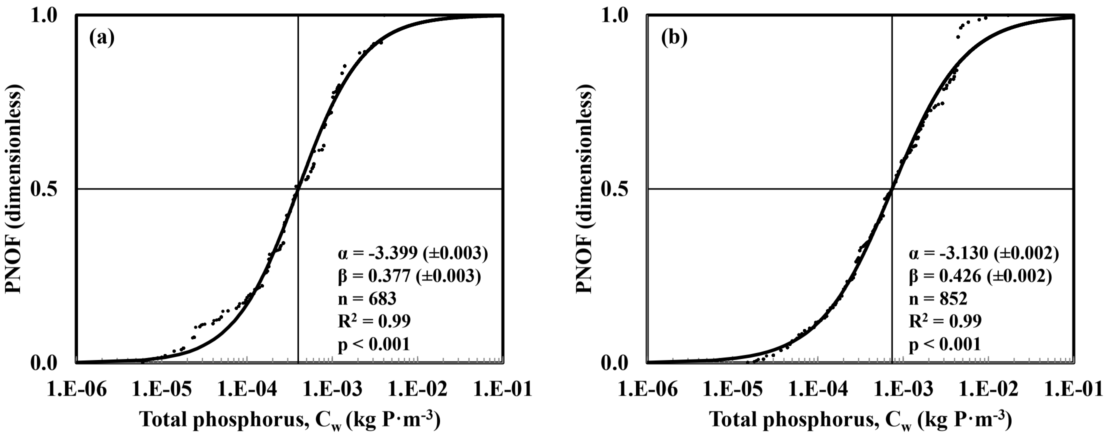

Figure 6.1 *Species sensitivity distributions (SSDs) of the potentially not occurring fraction of heterotrophic species (PNOF) and total P, illustrated by the log-logistic regression* $PNOF_w = \frac{1}{1+e^{-\frac{(log_{10}C_w - \alpha_w)}{\beta_w}}}$ *(see details in appendix 6.1). Coefficients α and β (± standard error), number of species n,* R^2 *and p value of the regression in shown for* ***(a)*** *lakes and* ***(b)*** *streams SSDs.*

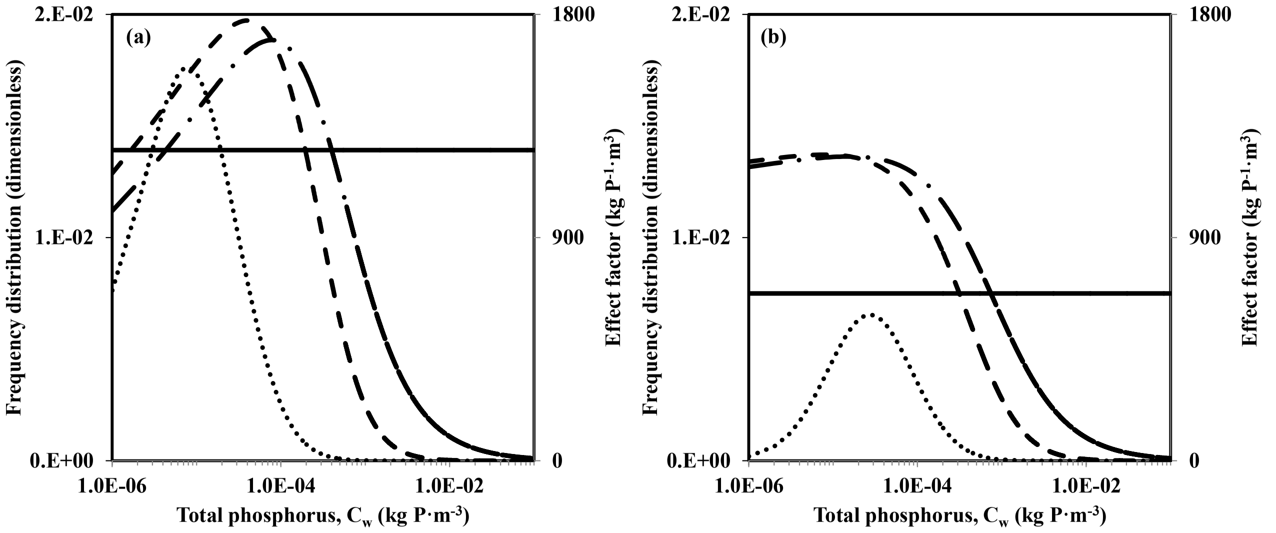

__Figure 6.2__ The probability density function (round-dotted, left axis) of TP concentration ($C_{w,j}$) and the marginal (dashed), linear (continuous), and average (dashed-dotted) effect factors (right axis) as a function of $C_{w,j}$ levels for (a) lake and (b) stream heterotrophs.

6.3.2 Model choice and spatial variability

River basin CFs for lakes were, on average, approximately 1.2 orders of magnitude higher than those for streams, irrespective of effect model type (Figure 6.3, see results of the ANOVA in Table S6.3.4). Additionally, average river basin CFs based on the linear model were significantly lower than those based on the average model (Figure 6.3a); yet no differences were found between the two concentration-dependent effect models. The differences between CFs derived with the average and linear effect factors for lakes are evident in grids occupying the Po and the Scheldt river basins, for example (Figure S6.3.1b,c). CF and NS results based on the three effect models are reported per river basin in Tables S6.3.1 and S6.3.2, respectively. Over half of the total variance of the ANOVA (R^2 = 56%, S6.3.4) was explained by freshwater type (sum of squares = 134.71) and to effect model type (sum of squares = 1.62). The relative contribution of freshwater type (0.55, S6.3.4) to the total variance of the ANOVA was higher than that of model type (0.01). The remaining variance originates from the variability within-samples, namely spatial variability.

This spatial variability across CFs was primarily driven by the variability across fate factors and, to a lesser extent, to the variability across effect factors (Table 6.1). Ultimately, the least variability was found in CFs derived using the linear effect model (as the variability is solely due to fate factors) and the highest variability was found in CFs derived with the marginal effect model for streams.

6.4 Discussion

6.4.1 Influence of freshwater type

Higher CFs for lakes are attributed to higher fate factors and effect factors for that freshwater type. Regarding fate, P is retained in the water column of lakes for longer periods since they have a longer hydraulic residence time of water in grid cells compared to streams (Helmes *et al.*, 2012). Regarding effect, the higher taxonomic similarity of lake species compared to those in streams prompt individual responses of species to TP shifts to be more homogeneous in the former than in the latter (Hof *et al.*, 2008). Accordingly, since the characterization model is based on the response of the overall heterotrophic species community (represented by PNOF), we find that CFs are greater if they are based on lakes than on streams.

6.4.2 Influence of effect model

Concentration-dependent effect factors are higher than the linear factors at lake concentrations from $0.5 \cdot 10^{-5}$ kg P·m^{-3} to $4.0 \cdot 10^{-4}$ kg P·m^{-3} or stream concentrations from $1.0 \cdot 10^{-6}$ kg P·m^{-3} to $7.0 \cdot 10^{-4}$ kg P·m^{-3}. Given that current TP levels in European freshwater bodies are generally within those ranges, the linear model underestimates the emission impacts compared to those based on average changes in the PNOF.

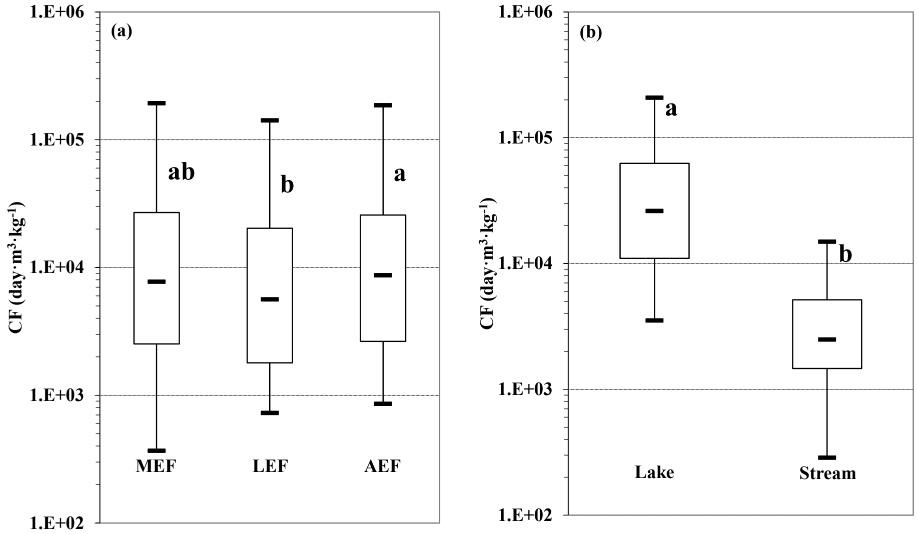

Figure 6.3 *Whisker plot (2.5th, 25th, 50th, 75th, and 97.5th percentiles) of river basin characterization factors (CF) based on marginal (MEF), linear (LEF), and average (AEF) effect factors for* ***(a)*** *lakes and* ***(a)*** *streams. Different lower case letters represent means that are significantly different from one another (at a 95% confidence level) using Tukey pairwise comparison test following the analysis of variance (ANOVA,* S6.3.4*).*

Under current trophic conditions, the differences between the marginal and the average effect models are minimal. As a result, our study did not detect significant differences between CF results determined with the two models. Had TP levels been higher than today (above $1.0 \cdot 10^{-4}$ kg P·m^{-3}, for example), those differences may have been revealed since the marginal effect model estimates little damage from P discharges into previously-eutrophied freshwater bodies compared with the average model (Huijbregts *et al.*, 2011).

Table 6.1 *Fate, effect, and characterization factor variability across river basins expressed as the ratio between the 97.5th / 2.5th values of river-basin characterization factors.*

	Lake			Stream		
Fate factor#, $\sum_j \mathrm{FF}_{i\rightarrow w,j}$, unit: day	48			19		
Effect factor#, $\overline{EF_{w,j}}$,	Marginal	Linear	Average	Marginal	Linear	Average
unit: kg $P^{-1}\cdot m^3$	1.5	1	1.3	11	1	4
Characterization factors#, $\sum_j FF_{i\rightarrow w,j} \cdot EF_{j,w}$, unit: day·kg $P^{-1}\cdot m^3$	51	48	56	69	19	41

River-basin values were obtained as the mean of grid-specific fate, effect, and characterization factors within each basin.

6.4.3 Spatial variability

Our results show that intrinsic differences between European basins account for nearly half of the variation between CFs. This adds to the existing body of evidence of the influence of spatial differentiation on characterization factor outcomes (Saad *et al.*, 2013, Wegener Sleeswijk & Heijungs, 2010). In this study, two main components contribute to the variability of fate factors: the grid-based residence time of P and then size of the river basin.

Grid cells with large fractions of water in lakes generally have a higher fate factor than river cells (as discussed above). Therefore, they likewise have high CF results (Helmes *et al.*, 2012), e.g. the East Estonian river basin. Furthermore, the fate factor of P is related to the number of downstream grid cells (Helmes *et al.*, 2012). Absent large lakes, small river basins (e.g. the Jucar and the Cyprus) will have smaller fate factors than large river basins (e.g. the Danube and the Elbe).

6.4.4 Model uncertainties

We employed the maximum TP concentration at which the species was confirmed to be present to derive PNOF – TP relationships. Using the maximum TP level is motivated by the fact that certain species may be subjected to P stress even in relatively unpolluted systems, where P concentrations are low. Nevertheless, P is also an essential nutrient to living cells and the maximum diversity of genera was found in Dutch streams at TP level equal to $1.0\cdot10^{-4}$ kg $P\cdot m^{-3}$, for example (Struijs *et al.*, 2011b). In this study, we quantify the impact of eutrophication not as the decrease in species richness in a freshwater community but by the cumulative decrease in each species occurrences. The latter can commence at TP levels much lower than the former.

We used TP concentrations from neighboring monitoring stations to account for the lack of monitoring data in certain grids. For 34% and 83% of European grid cells, we located at least one lake and stream monitoring station, respectively. The lower number of grid cells that have monitored lake concentrations compared to streams is due to the lower level of spatial detail outlined by the technical EEA guidelines for lakes (i.e. one sample every 1,750km^2) compared to streams (i.e. one sample every 1,000km^2). In any case, these different monitoring guidelines did not result in different variability in TP levels between the two freshwater types as the coefficient of variation across grid $\log_{10}$-transformed TP levels is nearly the same: 0.12 in lakes and 0.13 in streams. The extrapolation of monitoring TP data to non-monitored grid cells was a necessary step in the effect model, since the CF is the summation of the impacts on cells in and downstream of the cell of emission. Stronger monitoring efforts would be necessary (especially in lakes) in order to avoid extrapolation of TP levels to non-monitored European areas.

The TP levels used to derive our EFs (median of TP concentration in grids equals $1\cdot10^{-4}$ kg P$\cdot$m^{-3}) were generally lower than those applied by Struijs *et al.* (2011a), where the median TP in river catchments was $3.75\cdot10^{-3}$ kg P$\cdot$m^{-3}. As a result, average CFs across river basins was 2.2 times lower in our study than those reported for emissions to water from sewage treatment plants. (Note that this comparison is made for stream-based, MEF only.) We attribute this difference to the fact that Struijs *et al.* (2011a) use monitoring data from the 1980s to 2005, when streams were likely more P-enriched than they were in recent years. Lower, recent TP concentrations are attributed to successful reduction of P discharges by controlling emissions from wastewater treatment plants and the use of detergents based on phosphates (EEA, 2010, Millennium Ecosystem Assessment, 2005). In addition to the effect model, the fate factors we used in this study are lower than those reported by Struijs *et al.* (2011a) the fate factors we employed include estimates of P losses through water use and retention (Helmes *et al.*, 2012).

Another uncertainty in the effect model refers to the taxonomic level of species described by the PNOF – TP relationships. In this study, we used records at the species level while Struijs *et al.* (2011b) derive relationships by employing a higher (genus) taxonomic level. As evidence of stream impairment was hindered when family but not species taxonomic levels were used as the indicator of impact (Lenat & Resh, 2001), this may also have been the case for PNOF – TP relationships we employ since the slope of the logistic function we employ is steeper than the genera-based function employed by Struijs *et al.* (2011b). Ultimately, the impact of a stressor will be more easily perceived at the species rather than genus or family levels. In the latter, the loss of the genus or the family group would only occur when the last remaining species of that higher taxonomic group no longer occurred.

Our study derives CFs for emissions of P to water but not to soil. Characterization models where the fate from soil to water is included were developed by previous eutrophication models in LCIA (Huijbregts & Seppala, 2001, Seppälä *et al.*, 2004, Struijs *et al.*, 2011a) and, recently, it has been suggested that typically 10% of the P emitted to soil reaches water bodies (Bouwman *et al.*, 2009).

6.4.5 Implications

We tested the influence of effect models and freshwater types on characterization factors describing the impacts of P emissions to freshwater on the PNOF of heterotrophs. This test was performed for inland water bodies in temperate Europe. Our results show that CF results are influenced by both freshwater type (primarily) and effect model choices. However, CFs are also strongly influenced by the spatial variability in fate factors, thereby suggesting that spatially explicit methodologies in LCIA are crucial for an accurate assessment of phosphorus emission impacts in freshwater systems. This methodological effort has also commenced in the inventory phase of LCA (Geyer *et al.*, 2013, Tessum *et al.*, 2012). As LCIA continues to develop spatially-explicit effect models, it is important to test the influence of the different types of effect models and the main drivers of CF variability across their spatial units for other impact categories as well.

ACKNOWLEDGMENTS

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Chapter 7

Combined ecological risks of nitrogen and phosphorus in European freshwaters

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ABSTRACT

Eutrophication is a key water quality issue triggered by increasing nutrient levels in many lakes and streams, thereby posing risks to aquatic biota. In order to improve water quality and to realize a good ecological status, the European Water Framework Directive requires that the quality of freshwater bodies in member states are monitored. In this study, we predict the ecological risks of invertebrate species losses due to nitrogen and phosphorus pollution in European lakes and streams from 1985 to 2011. This risk indicates the probability that an invertebrate species within a community assemblage may become absent due to nutrient stress. Our results show that the ecological risk in streams and in lakes decreased in respectively 38% and 22% of river basins during the twenty-six monitored years. In addition, we find that the risk from nitrogen stress surpassed that of phosphorus in both freshwater systems during the studied period. The ecological risk framework can be applied to identify which river basins are most subjected to risks of invertebrate absences and what are the main stressors driving eutrophication impacts.

7.1 Introduction

The “limiting nutrient” concept, following Liebig’s Law of the Minimum, was based on experiments testing the effects of added nutrients on crop performance (van der Ploeg *et al.*, 1999). Later, the concept was extended to productivity-based experiments for eutrophication research, such as those testing the effects of nutrient surplus on chlorophyll concentration or biomass productivity (Allgeier *et al.*, 2011, Elser *et al.*, 2007). Despite the benefit prompted by the increase in the availability of a resource, such as productivity stimulated by nutrient increases, a further increase in the same resource availability could cause ecosystem damage, such as a shift in species composition (Odum *et al.*, 1979).

Eutrophication in freshwater is mainly triggered by agricultural and urban discharges of nitrogen, N, and phosphorus, P (Bouwman *et al.*, 2009). On one hand, the increase in nutrient availability generally increases primary production and, thus, the availability of food to planktivores and herbivores (Carpenter *et al.*, 1985). On the other hand, it may lead to it may also lead decreases in food quality and increased predation by secondary consumers (Carpenter *et al.*, 1985, Grimm & Fisher, 1989).

Besides changes in trophic cascades, increases in primary production may trigger decreasing water transparency and light availability, thereby eliciting competing phytoplankton to release allelochemicals, particularly cyanobacteria (Leflaive & Ten-Hage, 2007). Furthermore, enhanced decomposition of nuisance algae may generate hypoxic or (in extreme cases) anoxic conditions in aquatic systems (Carpenter *et al.*, 1998). Ultimately, the presence of oxygen depleted conditions, exposure to toxins released by phytoplankton, and shifts in food availability may be harmful to invertebrates (Camargo & Alonso, 2006a, Correll, 1998).

As a result of increasing N and P flows, eutrophication is given as one of the primary issues of freshwater systems (Millennium Ecosystem Assessment, 2005). However, eutrophication is a complex issue as it encompasses potential feedback mechanisms (van Donk & van de Bund, 2002), non-linear responses of primary production to trophic conditions (Genkai-Kato & Carpenter, 2005), and synergistic effects of nitrogen and phosphorus surplus on primary production (Elser *et al.*, 2000). The mechanisms driving primary productivity can be examined by analyzing past nutrient level patterns (Anderson, 1998) or nutrient stoichiometry changes (Glibert, 2012), ecological modeling (Genkai-Kato & Carpenter, 2005), or via nutrient addition experiments (Schindler, 1977). Complementary to mechanistic models, ecological indicators may be used to underpin the effects of eutrophication on species and provide environmental protection agencies with guidelines for the improvement and the maintenance of water quality (Smith *et al.*, 2007).

Indicators of eutrophication based on the performance of invertebrates may be less certain than those based on autotrophic species since consumer organisms are not directly affected by N and P concentrations as are photosynthesizing organisms (Johnson *et al.*, 2014). However, they are particularly useful to environmental agencies because they are extensively monitored (Growns *et al.*, 1997). One example of a water quality indicator are ecological quality ratios (EQRs) where different biological parameters (e.g. composition of invertebrate species) are compared with a reference representing minimum impairment (Clarke, 2013). The EQR is advised under the European Union Water Framework Directive (2000) because it is a clear way to identify and communicate about the overall health of the monitored freshwater body. Nevertheless, this indicator does not detect the specific cause of impairment.

In the case of eutrophication, the estimation of the overall health quality of freshwater needs also to uncover what the main cause of impairment is (namely, N and P). Therefore, an ecological indicator that allows for estimation of the ecosystem health as well as for identification of the source of impairment may provide environmental agencies with the tools to recognize impaired areas and to target the source of the issue. In this study, we propose an indicator for ecological impairment of freshwaters subjected to eutrophication. This indicator, defined as ecological risk (ER) is currently employed in the field of ecotoxicology (Fedorenkova *et al.*, 2012, van Straalen, 2002) and, in our case, is interpreted as the probability that a randomly chosen species belonging to an invertebrate species assemblage may not be present as a result of nutrient stress, namely N and P.

To that end, we employ monitoring data on nutrient concentrations and stressor – response relationships to quantify the risks of freshwater ecosystem stress triggered by high N and P concentrations. The ER is estimated separately for temperate European lakes and streams and on an yearly basis. Our study considers the risk to lakes and streams separately because they differ considerably with respect to water and nutrient cycling and their sources of energy supply (Doi, 2009).

7.2 Material and methods

7.2.1 Ecological risk (ER)

The risk posed to a group of species depends upon the sensitivity of each species to the stressor of concern and the probability that the species are subjected to the stressor (Figure 7.1). Thus, ER (dimensionless) is the definite integral

$$ER_i = \int_{-\infty}^{\infty} PDF(x) \cdot CDF(x)\, dx \qquad (7.1)$$

where PDF is the probability density function of the stressor i of ^{10}log concentration x (e.g. NO_3 or total P) and CDF is the cumulative distribution function of the sensitivity of species to increasing x (Fedorenkova *et al.*, 2012, van Straalen, 2002) . The effects of different stressors can be added in order to estimate the total ER to species as

$$ER_T = 1 - \sum_i (1 - ER_i) \qquad (7.2)$$

where ER_i is the individual ER of stressors i (Fedorenkova *et al.*, 2012). In our case, the ecological risks are calculated for two stressors (NO_3 and TP) and in two freshwater types (i.e. lakes and streams) in different European river basins (total of 88) per year (from 1985 to 2011). Finally, we used linear regression to test if the ER_T changed with time in each river basin.

The ecological risks posed by NO_3 and TP are hereafter referred to ER_N and ER_P, respectively. This relationship assumes an additive effect of ER_N and ER_P on species and it assumes no interaction between stressors (van Straalen, 2002) as there appears to be an additive effect of high resource supply (i.e. nutrients) in observational field studies (Harpole & Tilman, 2007). We focus on TP and NO_3 as indicators for P and N stress since they are commonly monitored by water quality programs (Lewis *et al.*, 2011).

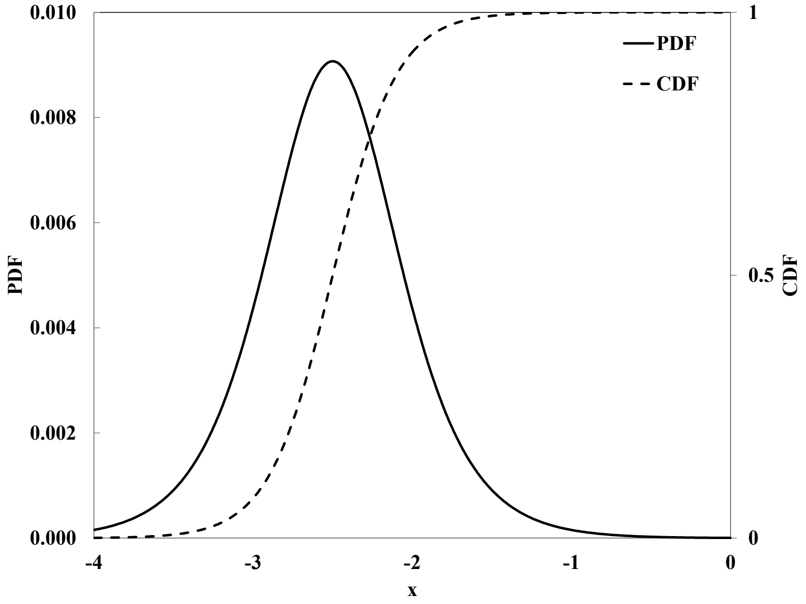


Figure 7.1. *Illustration of ecological risk (ER) defined as the area under the probability density function (PDF) of stressor* ^{10}*log concentration x and the cumulative distribution function of the cumulative fraction of absent species with x, adapted from Fedorenkova et al. (2012). In this example, the* α_c *and* β_c *coefficients of the PDF are -0.25 and 0.28 and the* α *and* β *coefficients of the CDF are -2.5 and 0.20, respectively.*

7.2.2 Cumulative distribution function (CDF)

With increasing x, an increasing number of species no longer tolerant to high stressor levels is expected (illustrated by the dashed line in Figure 7.1). The sensitivity to x can be illustrated in different ways, such as decreasing frequency of occurrence or reproduction, increasing mortality, among others. Ultimately, a species subjected to high enough stressor level x will no longer be able to subsist in the environment. Here, the tolerance to x is defined as the threshold level at which an individual species is no longer present in field surveys.

To attain the CDF, species-specific maximum tolerance x levels were ordered from low to high values (highest being the species most tolerant to x) and ranked from zero to one. CDF (dimensionless) was then fitted to a logistic describing the fraction of species becoming absent with increasing x levels as

$$CDF(x) = \frac{1}{1+exp^{-\left(\frac{x-\alpha}{\beta}\right)}} \qquad (7.3)$$

where the coefficients α represents the ^{10}log concentration at which 50% of the all species become absent because of nutrient excess, also called location parameter, and β represents the slope of the CDF. (Both coefficients are dimensionless.) This function was determined for the two stressors (i.e. NO_3 and TP) in two freshwater types (i.e. lake or stream).

The underlying data on invertebrate species-specific maximum TP tolerance was obtained from Azevedo *et al.* (2013a). The data consisted of a collection of peer-reviewed surveys whereby the presence of heterotrophs was recorded in the field alongside the TP concentration in temperate lakes or streams. The confirmation that a species was present at a given TP concentration was either given by confirmation of its presence but also by non-zero accounts of abundance, density or mass, for example. The maximum level at which invertebrate species was confirmed to be present was employed in the derivation of the CDF. The same procedure described by Azevedo et al. (2013a) was employed in our study in order to determine the maximum tolerance to NO_3 of species inhabiting temperate lakes and streams and, thus, to derive the CDF for NO_3. Species-specific data on maximum concentrations of NO_3 and TP at which each species was present are available in appendix S7.1 of the Supporting Information.

7.2.3 Probability density function (PDF)

The probability of a stressor being found at a concentration x (illustrated by the continuous line in Figure 7.1) can be described by a PDF of a logistic curve as

$$PDF(x) = \frac{exp^{-\left(\frac{x-\alpha_C}{\beta_C}\right)}}{\beta_C \cdot \left[1+exp^{-\left(\frac{x-\alpha_C}{\beta_C}\right)}\right]^2} \qquad (7.4)$$

where α_c and β_c are, respectively, mean and the slope of ^{10}log-transformed stressor concentrations x. The slope β_c is equal to $\frac{\sigma\sqrt{3}}{\pi}$, where σ is the standard deviation of ^{10}log-transformed stressor concentrations.

To derive the PDFs of NO_3 and TP per river basin, we used mean annual concentration data reported by the European Environment Agency, EEA (2013b), per monitoring station from 1985 to 2011 within each river basin of the European temperate zone. We employed the river basin delineation reported by the EEA (2012) and temperate freshwaters as defined by the major freshwater habitat types (MHT) of the Freshwater Ecoregions of the World (FEOW) project (http://www.feow.org/). Each monitoring station was allocated to its respective river basin based on its geographic coordinate (see summary statistics of river basins in appendix S7.2 and river basin delineation in appendix S7.3).

7.3 Results

The number of species available for the derivation of the CDFs varied from 390 (for NO_3 in lakes) to 804 (for TP in streams). The lowest maximum tolerance levels varied from 0.03 mg N/L to 27 mg N/L for NO_3 and 0.01 to 17 mg P/L (appendix S1), respectively. Our results show that the tolerance to N and P levels is lower in lakes than in streams ($\alpha_{Lake,TP} < \alpha_{Stream,TP}$ and $\alpha_{Lake,NO_3} < \alpha_{Stream,NO_3}$, Figure 7.2). Additionally, the sensitivity to increasing nutrient levels is higher in lakes than in streams, as shown by steeper slopes of the CDF ($\beta_{Lake,TP} < \beta_{Stream,TP}$ and $\beta_{Lake,NO_3} < \beta_{Stream,NO_3}$).

The number of stations monitored for nutrient levels increased in both lake and stream systems over the 26 monitored years. From 1985 to 2011, the number of monitored lakes increased from 2 to 25 while the number of monitored streams increased from 8 to 68 (appendix S7.2). Of 51 river basins, 10 basins comprised lake ER_N decreasing with time (slope $S < 0$ at a 95% confidence level, Figure 7.3a) and 39 basins were not subjected to significant changes in ER_N. Likewise, the number of basins whereby lake ER_P decreased with time was rather low (total of 11) compared with the number of unchanging ER_P (total of 42). Accordingly, most basins show no change in lake ER_T (total of 33, Figure 7.3c) over time. Similarly to lakes, most basins show no change in stream ER_T (total of 42, Figure 7.4c) with time. Nevertheless, the number of basins with decreasing stream ER_N, ER_P, and ER_T relative to the total number of estimated basins was considerably higher than that in lakes. For example, 11 of 42 basins were subjected to a decrease in lake ER_T (Figure 7.3b) while the same was only observed in 30 of 44 basins for streams (Figure 7.4c).

The ER_N (Figure 7.5a) was predominantly higher than ER_P in streams (Figure 7.5b). For example, from 2001 to 2011, 46 to 77% of river basins comprised ER_N higher than ER_P in a given year. However, the opposite pattern is observed in streams. Over the same period, 11 to 52% of river basins in a given year comprised ER_N above ER_P. We also found a strong variability in the ER across European river basins, especially for ER_N. This can be seen as the range of 95th and 5th percentiles of ER_N in European basins in a given year were, on average, 58.1% in lakes and 45.1% in streams (Figure 7.5a) while the range in of 95th and 5th percentiles of ER_P were, on average, 25.3% in lakes and 31.3% in streams (Figure 7.5b). The increase in monitoring efforts over the years prompted the increasing variability across river basins, Figure 7.5c.

7.4 Discussion

7.4.1 Lakes versus streams

Streams comprise a shorter hydraulic residence time than lakes and, thus, the former may serve as an instantaneous indicator of recent nutrient discharges. The decrease in ER_P in streams (which occurred in 38% of river basins) can be attributed to successful efforts to reduce P discharges to freshwater by controlling wastewater emissions and by the use of banning phosphates in detergents (EEA, 2010, Glibert, 2012). By contrast, since lakes are subjected to continuous recycling and uplift of P in sediments that have already been enriched in the past (Marsden, 1989), the decrease in lake ER_P was observed in only 20% of European river basins.

Despite the success in reducing P discharges from wastewater, this management strategy alone may not solve issues of freshwater eutrophication in Europe because ER_P and ER_N remained constant in a large number of basins. Discharges from agriculture account for an important share of freshwater eutrophication impacts and, thus, additional stream reductions will be more easily achieved if emissions from non-point sources (e.g. agricultural fertilizers) use are controlled as well (EEA, 2010).

Stream fauna appeared to be less vulnerable to high nutrient levels ($\alpha_{Lake} < \alpha_{Stream}$, Figure 7.1). This also corresponds with the lower N and P levels defining trophic state thresholds for lakes than for streams (Smith *et al.*, 1999). Additionally, lake invertebrates are more sensitive to increasing nutrient levels compared to streams ($\beta_{Lake} < \beta_{Stream}$, Figure 7.1). Azevedo *et* *al.* (2013a) suggest that this higher sensitivity is due to the fact that insects in lakes (corresponding to 42% of the invertebrates) respond to increasing nutrient stress more similarly to one another than those in streams (corresponding to 64% of invertebrates) due to the higher β-diversity in the latter (see also Hof *et al.*, 2008). A second reason may be due to the fact that streams are subjected to larger input from adjacent areas (namely, terrestrial systems) than lakes (Johnson *et al.*, 2014). Since streams may be more subjected to nutrient input from terrestrial systems, there is a possibility that species may have adapted to corresponding nutrient levels. (The adaptation of species to the environmental conditions they are exposed to through time is depicted by the evolutionary species pool hypothesis (Pither & Aarssen, 2005). Despite the higher sensitivity of lake invertebrates to increasing nutrient concentrations, efforts to monitor nutrient levels in lakes were considerably less than in streams. We attribute that to the higher level of spatial detail required in the guidelines of monitoring data, whereby the sampling per covered area in streams is more frequent than in lakes (Nixon *et al.*, 1998).

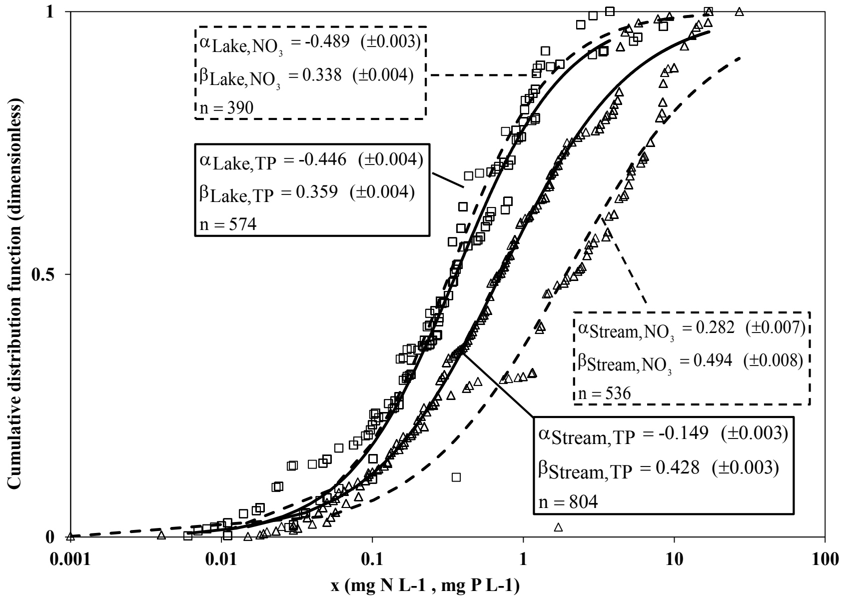


Figure 7.2 *Cumulative distribution functions of invertebrate species losses and nitrogen and phosphorus concentration x. The sample size and standard error (in brackets) are shown following the coefficient values. Triangles and squares represent lakes and streams and dashed and continuous lines represent* NO_3 *and total phosphorus (TP), respectively.*

7.4.2 Nitrogen versus phosphorus

The ecological risk of N stress is considerably higher than the ecological risk of P stress in both freshwater systems (Figure 7.4a,b). Here, we propose a number of reasons for higher risks posed by nitrogen in lakes. Sterner (2011) observed high NO_3 values in Lake Superior and attributed these high values to two common biogeochemical patterns resulting from their low primary production rates: the slow uptake of NO_3 due to low nutrient demand and the low denitrification rates due to low concentrations of organic carbon and infrequent low redox conditions. The excess of N supply compared to P was also indicated by the lower stoichiometric N:P ratios in herbivore tissue compared to the organic matter on which they feed (Elser *et al.*, 2000). The fact that herbivores dispose of nitrogen available in their food supply to a greater extent than they dispose of phosphorus in lakes (Elser *et al.*, 2000, Glibert, 2012) might suggest that nitrogen is not limited but saturated in that freshwater type. Ultimately, the excess of N available in food supply may prompt N stress to herbivores.

Finally, the relatively high ER_N in lakes can be possibly attributed to the high atmospheric N deposition rates, particularly in midwestern Europe (Dentener *et al.*, 2006b). This region also shows the highest ER_{N+P}. The differentiated atmospheric deposition patterns across European landscapes may have also prompted the higher variability in river basin ER_N compared to that of ER_P.

It is important, however, to discern the indicators of ecological impact due to nutrient stress. In this study, we expect nitrogen to be the nutrient in excess due to the fact that the ecological risk to invertebrate species posed by nitrogen was found to be greater than the risk posed by phosphorus. This contrasts with previous studies, where primary productivity increase in temperate lakes in Canada by phosphorus surplus (Schindler, 1977, Schindler, 2012). A decrease in macroinvertebrate families were driven by phosphorus more than by nitrogen (Weijters *et al.*, 2009), although our results may contrast to these since western Europe is subjected to higher atmospheric N depositions than the global average. As far as diversity of invertebrates is concerned, the question of whether nitrogen versus phosphorus control remains unanswered.

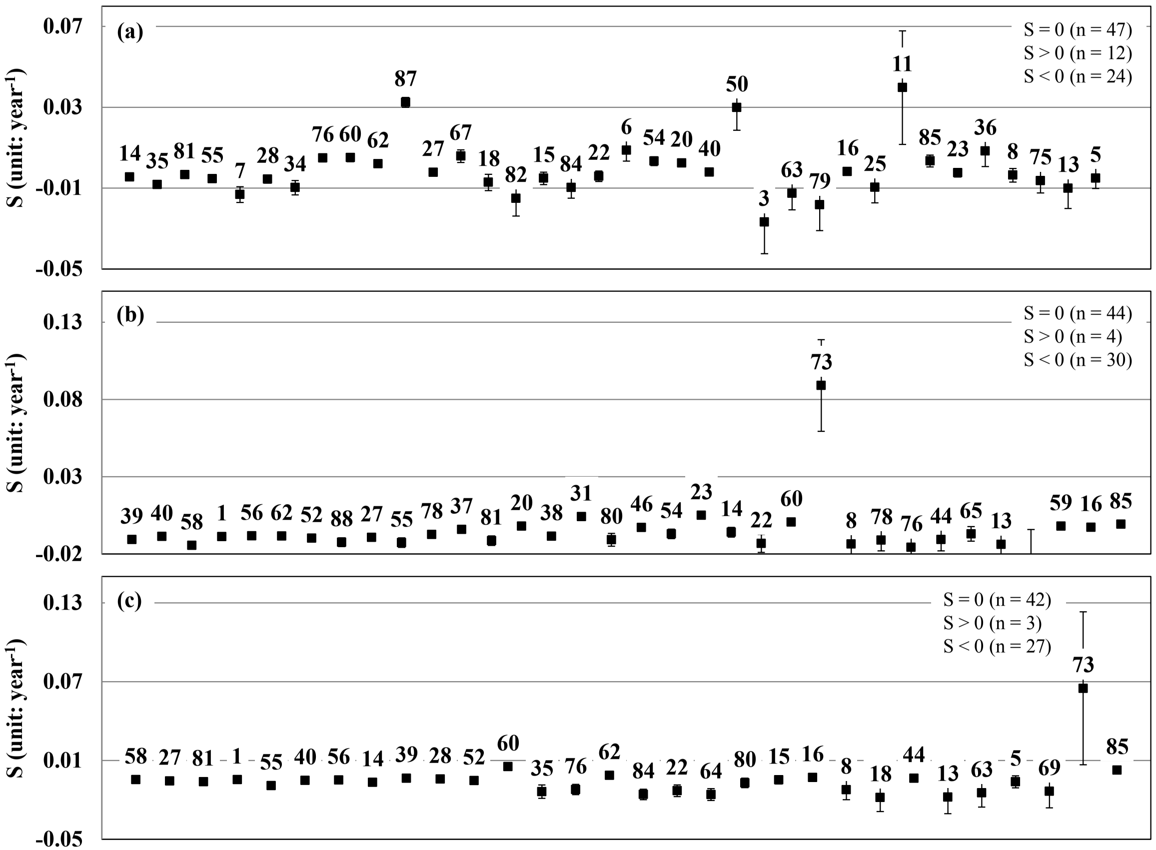


***Figure** 7.4 Results of the linear regression for ecological risk as a function of year (from 1985 to 2011) due to **(a)** nitrogen, **(b)** phosphorus, and **(c)** N+P stress in streams. The slope of the regression (S, with error bars showing the 95% confidence level) is shown for each basin number (the legend of basin names can be found in appendix S3). Slopes S which are higher, lower, and non-different than zero (p value < 0.05) are shown in the bottom right corner.*

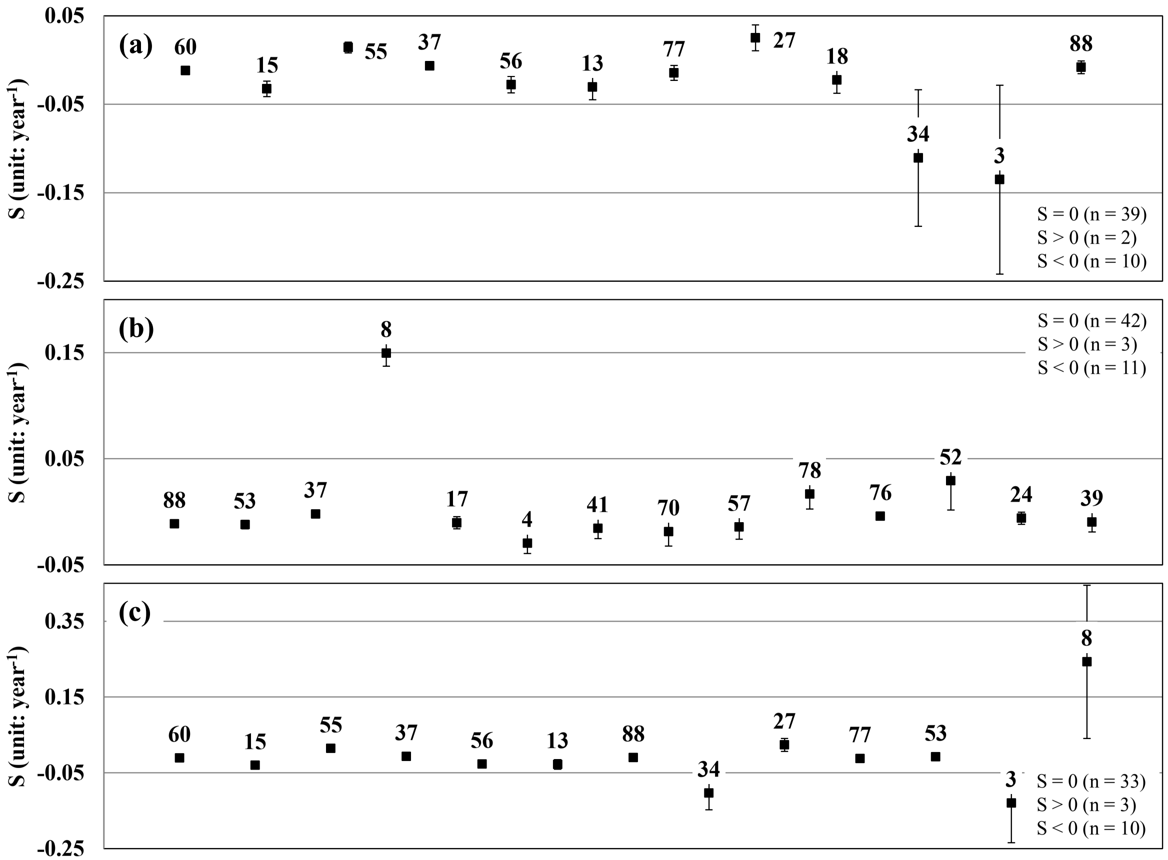


Figure* 7.3** *Results of the linear regression for ecological risk as a function of year (from 1985 to 2011) due to* ***(a) *nitrogen,* ***(b)*** *phosphorus, and* ***(c)*** *N+P stress in lakes. The slope of the regression (S, with error bars showing the 95% confidence level) is shown for each basin number (the legend of basin names can be found in table S7.3.1). Slopes S which are higher, lower, and non-different than zero (p value < 0.05) are shown in bottom right corner. Basins where the regression could not be determined (less than three sampled years) are not shown.*

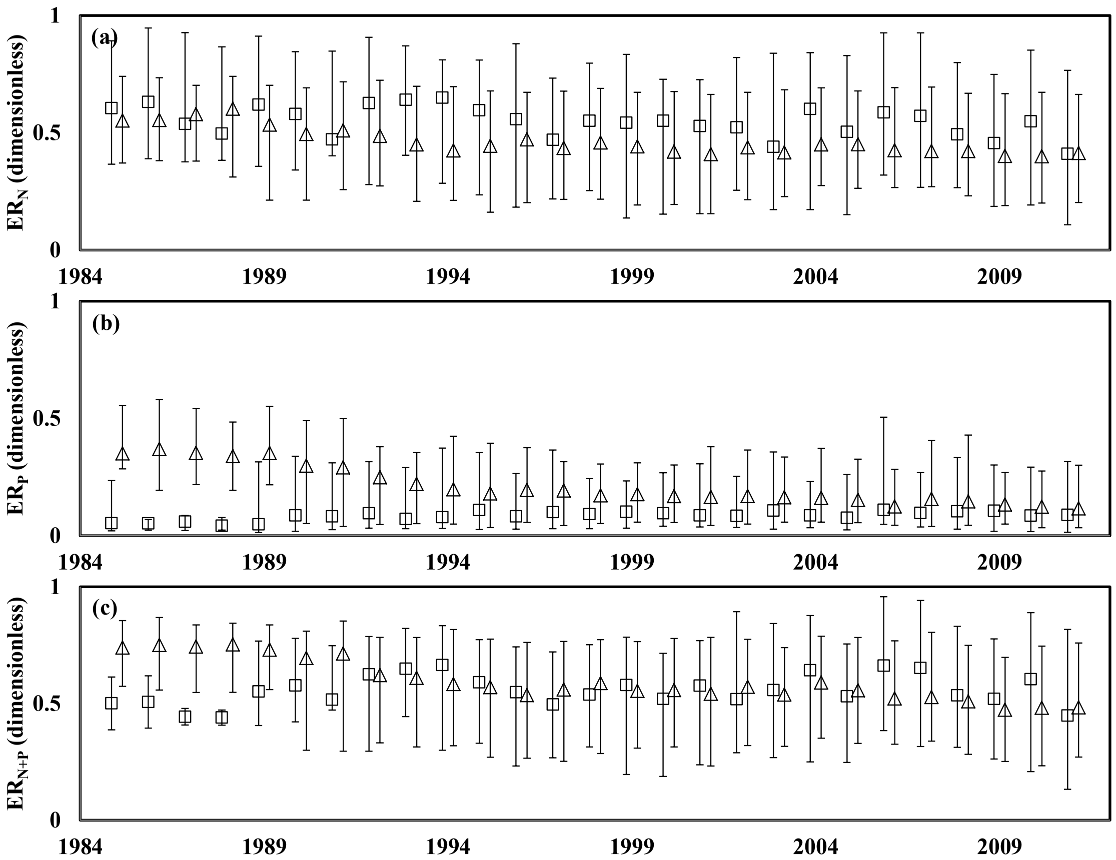


Figure* 7.5** *Ecological risk (ER) due to* ***(a) *N,* ***(b)*** *P, and* ***(c)*** *N+P from 1985 to 2011. Square and triangle symbols represent the median of ER in lakes and streams, respectively, and bars represent the 5th and 95th percentiles.*

7.4.3 Limitations

Non-additive effects of N and P have been confirmed for indicators of eutrophication related to productivity, such as primary productivity and autotrophic biomass, or levels of nutrient in water bodies compared with reference sites (Allgeier *et al.*, 2011, Dodds, 2006, Elser *et al.*, 2007). However, we are not aware of observational studies confirming interacting effects of N and P on diversity of invertebrate species in freshwaters. Similarly, Harpole & Tilman (2007) observed interactive effects of stressors on plant species losses in experimental studies but only an additive effect in observational studies. We do not rule out the possibility that there are interactive effects of N and P on invertebrate losses. However, as environmental concentrations in observational studies are not deliberately designed as are those in controlled experiments (Tilman, 1987), it is not possible to test this interaction based on our field survey study.

We use the same cumulative distribution function expressing the vulnerability of species towards high nutrient levels (expressed by the β coefficient) and their sensitivity to changes (expressed by the α coefficient) across the years and across river basins. We expect that this function is unlikely to change in such a short period of time as these are characteristics inherited during years of evolution, determined by differentiated exposures to hydrological and biogeochemical patterns in the two freshwater types (Azevedo *et al.*, 2013a).

Our study uses the maximum NO_3 and TP concentrations at which each invertebrate species was confirmed present and they represent the threshold whereby species are no longer tolerant to higher nutrient levels. However, field surveys may simply have been unable to detect the species at levels higher than this threshold (Azevedo *et al.*, 2013a), a characteristic that is common to presence-only studies of species occurrence (Walker & Cocks, 1991).

Furthermore, this study does not include potential invertebrate species absences as a result of decreasing food supply, resulting from nutrient depletion. Although nutrient depletion may alter species composition similarly to nutrient excess (Merritt *et al.*, 1984), such stress is not considered in our study because the issue of oligotrophication is not as prevalent as is eutrophication. We also assume that the species composition represented by the logistic functions is not influenced by other stressors, such as temperature, pH, etc.

7.4.4 Concluding remarks

Because the monitoring of biodiversity shifts can be costly, ecological indicators of water quality impairment should be an available tool for environmental agencies (Johnson *et al.*, 2014). In this study, we account for eutrophication risks triggering the absence of invertebrates. Here we focus on the potential absence of invertebrate species as this species group is frequently monitored (Growns *et al.*, 1997). But, most importantly, we focus on the species composition, not primary productivity.

We estimated the ecological risks due to N, P, and N+P stress to invertebrates in lakes and streams. Efforts to improve water quality in Europe should take into account that risks of absence of invertebrates due to excess of nutrients were generally triggered by high N levels, not P. Thus, a stricter control of nitrogen discharges to Europe inland waters is necessary in order to comply with the requirements of the WFD (James *et al.*, 2005). As water bodies in the European Union are required to achieve 'good ecological status' by 2015 (Water Framework Directive, 2000), this study helps providing a framework to identify which nutrients cause the highest risks of invertebrates species decreases and which European river basins are most subjected to such risks.

ACKNOWLEDGEMENTS

We thank Pieter M. F. Elshout for helping with data collection. This research was funded by the European Commission under the 7th Framework Programme on environment; ENV.2009.3.3.2.1: LC-IMPACT – Improved Life Cycle Impact Assessment methods (LCIA) for better sustainability assessment of technologies, grant agreement number 243827.

Chapter 8

General discussion

This thesis aimed at developing stressor – response relationships to understand biogeographical patterns of species communities and conduct impact assessments involving the following stressors: soil pH (chapters 2 and 3), ocean pH (chapter 4), and freshwater total phosphorus (TP) and NO_3 (chapters 5 to 7). This was attained by employing observational field data on species occurrence or experimental data concerning effects on their life processes.

This chapter is composed of three sections. The first conveys the limitations and uncertainties of the stressor – response relationships developed in chapters 2 to 7 (section 8.1). The second section comprises the interpretation and comparison of the main results of this thesis, namely some of the evolutionary patterns and inherent and human-driven processes that influence environmental nutrient levels and the impact on species. The third concludes with the main findings and implications of this thesis and recommendations for future research (section 8.3).

8.1 Uncertainties and limitations

Understanding the attributes of the stressor – response relationships is vital to the comprehension of relevant uncertainties and limitations. In the following, the uncertain aspects of the stressor – response relationships are described, followed by an evaluation of their possible implications.

8.1.1 Nutrient pollution, not nutrient depletion

This thesis addressed the impacts of nutrient pollution, namely its excess in the environment. If the same stressors would not have been subjected to increasing but decreasing stressor levels, the richness of species will be hampered all the same (Grime, 1973). For that reason, species richness is maximized at intermediate levels of stress and minimized at the two extremes. This phenomenon is defined as the intermediate disturbance hypothesis, IDH (Grime, 1973), and it seems to explain species responses to different biotic and abiotic stressors. According to the IDH, species were exposed to an environmental stress in the past (low, intermediate, or high levels). As a consequence of millions of years of evolution, few species adapted to low and high levels and many species adapted to intermediate levels. In this thesis, only the losses in biodiversity (indicated as richness or absence of species) as a result of increasing stressor levels were evaluated.

8.1.2 Community of species, not individual species

The ecological impacts of nutrient pollution were indicated for the species community rather than for specific (groups of) organisms. Accordingly, keystone, endemic, or commercially valued species are given the same importance in the stressor – response function as other species. Stressor – response curves based on specific species groups may prompt different results. For example, the stressor – response relationships developed for ecological effects of temperature revealed that the sensitivity of native species to warming of riverine waters appear to be higher than that of non-native (Leuven *et al.*, 2011), but see also cases of undifferentiated sensitivity between native and non-native species subjected to extended droughts (Collas *et al.*, 2014), chemical stressors (Fedorenkova *et al.*, 2013), or hypoxia (Elshout *et al.*, 2013).

Besides differences between individual species, there are also differences between species groups. In this thesis, macrophytes in temperate lakes appear to be more sensitive to TP increases (depicted by slope of the stressor – response curve) than phytoplankton (i.e. cyanobacteria, silicon and non-silicon based algae, Table S5.3.5), both of which are autotrophic species.

8.1.3 Variability across biogeographic units

Besides taxonomic variability, illustrated by differences between among stressor – response coefficients derived for different species groups, there can also be considerable spatial variability within biogeographic units. However, within spatial unit variability was not account for. When logistic relationships were developed at the ecoregion scale (Appendices S2.5 and S5.3), the number of species available for the derivation of the relationship decreased, thereby often resulting in unsuccessful fitting of the logistic regressions. For example, while the log-logistic relationship was successfully derived for autotrophs in (sub)tropical streams (chapter 5), relationships for autotrophs in streams were only successfully derived for two of four freshwater ecoregions of this habitat (Table S5.3.6). Ultimately, the use of more detailed biogeographical units (in this case, ecoregions) may prompt stressor – response functions that more accurately represent its species assemblage but it may also decrease the statistical power to derive regressions.

8.1.4 Confirmed presence, not confirmed absence

As an inherent attribute of presence-only observational field studies, the actual stressor level boundaries represent the range of concentration where each species was confirmed to be present, not confirmed to perish. Hence, it is not possible to determine if the minimum and maximum stressor level boundaries of a species represent indeed life-threatening conditions or if they are false confirmations of absences (Engel *et al.*, 2005, Pearce & Boyce, 2006, Tsoar *et al.*, 2007). False positives of species absences are an upshot of insufficient sampling or other environmental constraints or the nonexistence of stressor levels at the field beyond the surveyed range (Felzer *et al.*, 2009).

Insufficient sampling may be solved with standardization of protocols for surveys so as to guarantee that these are thorough enough to identify with more certainty that the species is not present beyond the surveyed range as a result of actual stress (Felzer *et al.*, 2009). Other constraining environmental variables, such as limited species dispersal, interaction with other stressors, historic events, or local extinctions may prompt a species to not be present in a surveyed area even though the levels of the stressor of concern are favorable (Felzer *et al.*, 2009). Absences as defined as potential habitats and, thus, species presences are a result of the realized habitats (Roelofs *et al.*, 2003). The difference between realized and potential habitats may also be triggered by the absence of stressor levels in the surveyed area. For example, while a plant occupying an acidic soil may have potential to survive in alkaline soils, such conditions are rarely realized in a survey.

8.1.5 Unaccountability of short term species adaptation

Since human interferences on nutrient biogeochemistry began many years ago, particularly during the Industrial and Green Revolutions (Smil, 2001, Smith, 1994), species have most likely been subjected to increasing stress levels years before the surveys used in this thesis were initiated. For example, large scale nutrient emissions have commenced earlier in the temperate zone of developed countries than elsewhere. If these short-term (i.e. years or centuries) past pollution events were severe enough to cause shifts in species assemblages, a short but intense natural selection (known as microevolution) may have taken place. For example, Trubina & Vorobeichik (2012) report that pollution may favor the maintenance of species adapted to high stressor levels even though the overall species density has decreased. In this thesis, it is not possible to determine the extent by which microevolution influenced the underlying data of species occurrences. As one example of long-term evolution being more dominant than that on the short-term, the species assemblage of (sub)tropical moist broadleaf forests encompass many more aluminum-tolerant species than other biomes, such as species of the Melastomataceae and Theaceae families (Hayde Gonzalez-Santana *et al.*, 2012). The selection of species tolerant to aluminum is unlikely to have occurred in the few centuries of large scale human interference since soil weathering and the formation of acidic soils in (sub)tropical areas is in the order of millions of years (Volkoff, 1998).

8.1.6 Unaccountability of multiple or possible interacting effects

The stressor – response relationships represent the effect of one stressor only. Thus, other effects triggered by the same stressor are not accounted for. For example, besides terrestrial acidification, atmospheric nitrogen emissions may cause increases in tropospheric ozone, both of which have been shown to have detrimental effects on the performance of species (Bobbink *et al.*, 2010, van Goethem *et al.*, 2013). Other impacts of nutrient stress may arise. For example, atmospheric CO_2 or freshwater N and P emissions may also affect certain ecosystem services, e.g. nutrient cycling (Jeffries & Ouimet, 2004, Miltner, 2010) or recreational activities, e.g. fishing (Carpenter *et al.*, 1998), or may cause secondary impacts or feedbacks to other species populations (Le Bagousse-Pinguet *et al.*, 2012).

Possible interacting effects between stressors were also not included. For example, the synergy between nitrogen and phosphorus have been thoroughly documented for impact assessments where the ecological response is based on primary productivity (Elser *et al.*, 2007, Lewis *et al.*, 2011). However, in a comparison between types of effects encountered in experimental and observational studies, Harpole & Tilman (2007) found that additive effects of different stressor types on species richness predominate in observational studies while interactive effects predominate on experimental ones.

8.2 Interpretation

8.2.1 Biogeography explaining stressor – response functions

Each species assemblage of the present is a result of a gradual change in environmental conditions of the past, whereby each of its constituents, the species, continually died out and disappeared while others were favored or adapted and, thus, persisted (Wallace, 1855). Since species assemblages today are a direct upshot of the exposure to stressors following historic events or geographical trends, e.g. a glacial age or latitudinal gradient (Pärtel, 2002), stressor – response relationships are able to describe how species assemblages respond to an environmental stressor at a present state. Therefore, the stressor – response relationships developed in this thesis allow for the comparison of the sensitivity to nutrient pollution across different stressors, ecosystems, or species groups.

The biogeochemical processes driven by climate and by geological events in the past have profound influences on the responses of ecosystems to stressors. These responses may be explained by the evolutionary species pool hypothesis (ESPH), whereby the persistence of certain environmental conditions will prompt the selection of species which are able to prevail under those conditions (Pither & Aarssen, 2005). Below, the optimal soil pH and freshwater TP conditions are explained by the ESPH. Further, the stressor – response relationships coefficients (α and β) are explained by the species composition embedded in each stressor – response relationship.

8.2.2 Coefficients of stressor – response functions

The high temperature and high precipitation patterns of low atmospheric pressure world zones prompts high soil weathering rates, thereby prompting the depletion of base cations (Matson *et al.*, 1999). Ultimately, (sub)tropical ecosystems, with the exception of (sub)tropical dry broadleaf forests, encompass low optimum pH values. This pattern also predominates in another low atmospheric pressure zone (around ±60º latitude), where temperate broadleaf mixed forests and boreal forests are found. By contrast, high atmospheric pressure zones (located between ±20º and ±35º and around ±90º of latitude), are covered by deserts and xeric shrublands, Mediterranean forests, woodland, and scrubs, and tundra and hence their soils comprise relatively high optimum pH (Table 2.1).

As opposed to streams, lakes are generally subjected to long water residence times and slow water currents. Additionally, deep lakes are subjected to lake stratification that conserves surface waters at high temperatures and rich in nutrients. These features prompt fast nutrient immobilization by photosynthesizing organisms in lakes (Carpenter *et al.*, 1998, Doi, 2009, Holtan *et al.*, 1988, Vannote *et al.*, 1980). The shape of streams, on the other hand, renders a stronger later connection to adjacent ecosystems (i.e. land) than does that of lakes (Johnson *et al.*, 2014). The fast depletion of available P and the lower input of terrestrial-derived P in lakes may have induced the low concentrations of P in lakes in the past, thereby favouring species which adapted or thrived under such conditions (as stated in the ESPH). Finally, this might explain why temperate lake P concentration at which autotrophic species richness is maximized today to be lower than that of streams (e.g., $C_{opt,lake} = 0.05$ and $C_{opt,stream} = 0.20$, chapter 5).

Ecosystems exposure to past stressor levels may reflect the optimal conditions they adapt afterwards, as discussed above, but may also affect the tolerance of the species assemblage to stressors today. This is reflected in the strong correlation between optimum pH and the pH at which the relative species richness (RSR) is 0.5, i.e. α, Figure 8.1(a). The same correlation also exists between the optimum concentration of TP and α, yet to a lower extent (p value = 0.07). Thus, not only does the ESPH explain the favoring of species assemblage at a specific optimum level, it also explains the favoring of a specific fraction of the same assemblage to a specific pH or TP condition, e.g. α.

Likewise, if the concentration of the stressor is changed, the fraction of the species in the assemblage will change accordingly. The tolerance of species assemblage to these changing stressor levels is depicted by the slope of the stressor – response curve (i.e. β). In terrestrial systems, the tolerance to acidic soils is negatively correlated with the tolerance to changing pH (correlation between optimum and β, p value = 0.04, Figure 8.1b). The same correlation occurs between optimum and β, yet to a lower extent (p value = 0.08, Figure 8.1b). On the contrary, there is no significant correlation between optimum TP and β (p value = 0.56, Figure 8.1b) or α and β (p value = 0.87, Figure 8.1c) for RSR – TP relationships in freshwater systems. For possible explanations of this discrepancy, it is important to review which ecosystems the different stressor – response relationships represent.

(Sub)tropical moist broadleaf forests encompass vascular plants which are tolerant to acidic conditions following historic exposure to low pH. However, these plants are also highly sensitive to soil acidity as the high temperature and moisture conditions wherein they subsist trigger (1) a higher mobility of pollutants and, added to the high metabolism of plants, culminate in a higher exposure of plants to pollutants (Zvereva *et al.*, 2008) and (2) a constant exposure of aluminum-sensitive new roots produced year-round (Wilcox *et al.*, 2004). As a consequence, it is possible that, below a certain pH, physiological processes are hampered, causing plants subsiding in acidic conditions to also be the most sensitive to increasing acidity. The higher sensitivity of low latitude was also reported elsewhere (Zvereva *et al.*, 2010, Zvereva *et al.*, 2008). In the case of freshwater systems, the correlation depicted in Figure 8.1 includes multiple ecosystems (lakes and streams distributed over four climatic zones) and two species groups (autotrophs and heterotrophs), which may have prompted no apparent trend between the β and the optimum TP and α.

In this thesis, three indicators of species community responses to nutrient pollution are applied: relative species richness (chapters 2 and 5), relative species absences (chapters 3, 6, and 7), and performance at different life processes (chapter 4). To estimate relative species richness, the number of present species was summed at individual stressor levels by using the species-specific minimum and maximum stressor levels at which each species was confirmed to be present (Figure 8.2a). Species absences were determined using the maximum stressor level value available for that species (i.e., lowest soil or marine pH or highest TP or NO_3 values), Figure 8.2b. The performance at different life processes was determined with species-specific half maximum effective concentrations, i.e. EC_{50}, and 10% maximum effective concentrations, i.e. EC_{10}, from manipulated experiments (Figure 8.2c). Hence, the stressor – response functions should be interpreted as the nutrient pollution driving (i) the decrease in relative species richness, (ii) the possible absence of a random species of the community, and (iii) the decrease in growth, mortality, or reproduction of a random species of the community, respectively. Despite the difference in the underlying data used to derive stressor – response relationships, there were no significant differences within α and within β of the stressor – response curves derived with species richness and species absence (Test 8.3.1 in Figure 8.3). This suggests that the stressor – response relationships developed in this thesis may be used interchangeably for applications to comparison of ecosystems, for effect analysis in LCIA, and for ERA. While comparing the sensitivity to changing levels of the four stressors studied in this thesis (i.e., soil and marine water pH and freshwater TP and NO_3), we found no significant differences between them (Test 8.3.2 in Figure 8.3).

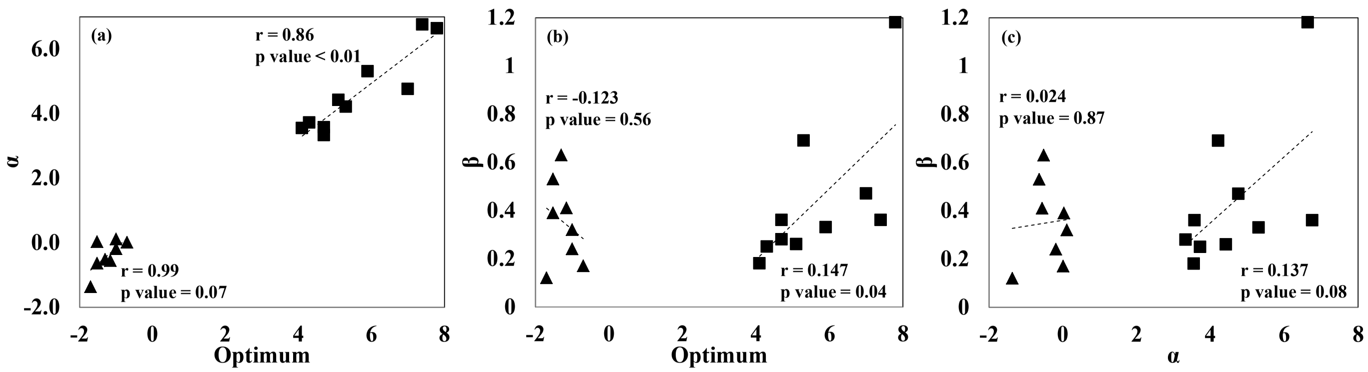


Figure 8.1 *Linear regression results between* ***(a)*** *optimum and α,* ***(b)*** *optimum and β, and* ***(c)*** *α and β coefficients. The slope (r) and p value (p) are shown next to correlation line. Squares and triangles illustrate coefficients for species richness – soil pH (chapter 2) and species richness – total phosphorus (chapter 5) relationships.*

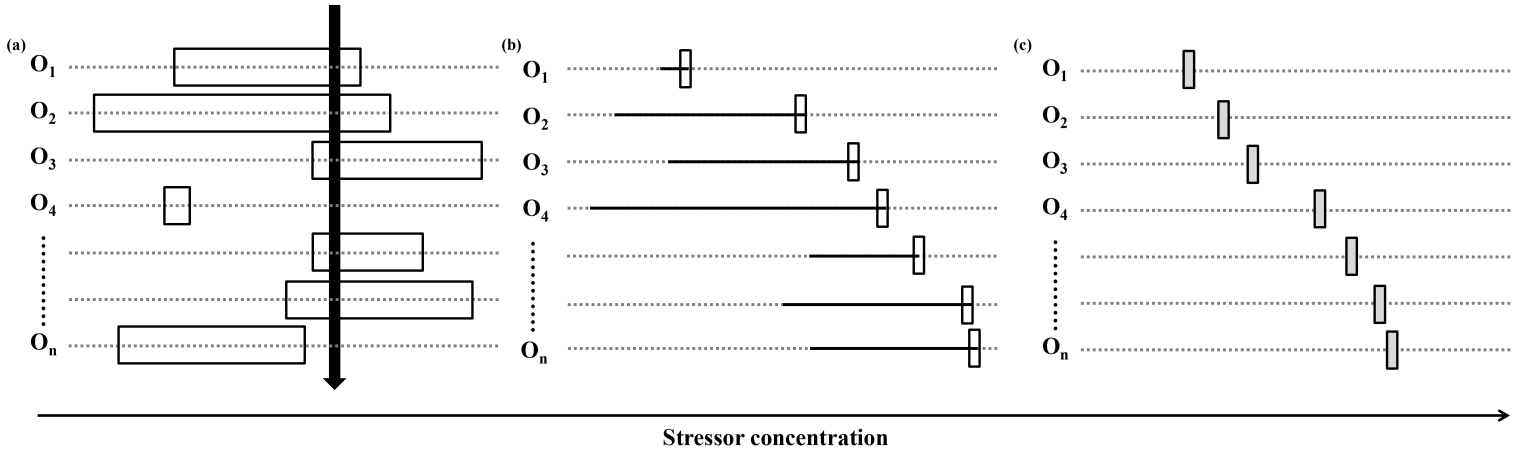
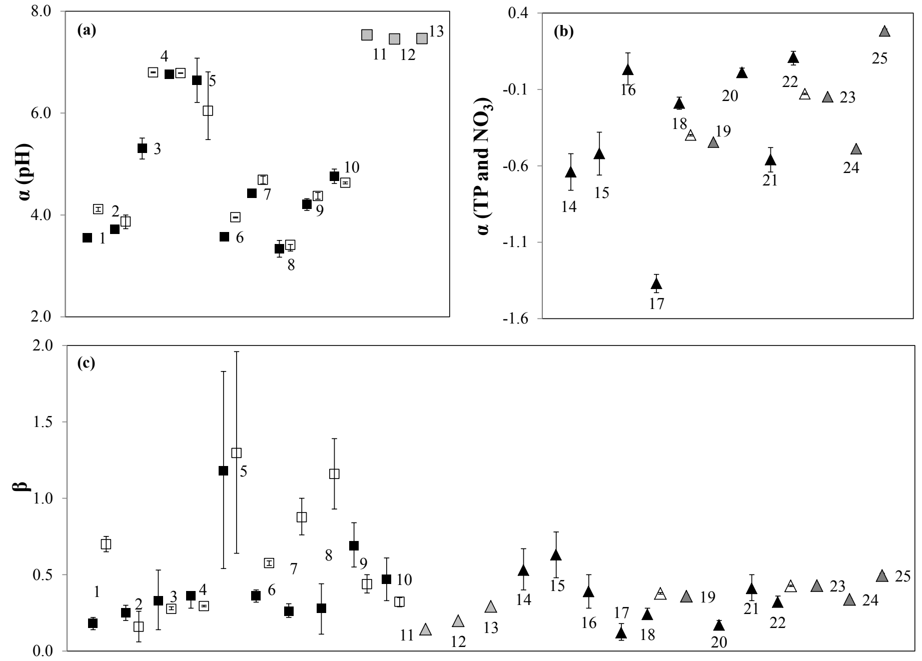


Figure 8.2 *Underlying data used in the derivation of stressor – response functions for* ***(a)*** *species richness,* ***(b)*** *potential species absence, and* ***(c)*** *potential affected fraction as a function of stressor concentration (horizontal arrow). The rectangles of* ***(a)*** *represent the stressor range at which the species was confirmed present and the vertical black arrow represent the sum of species presences at a specific stressor level. The rectangles in* ***(b)*** *represent maximum level concentration at which each species was confirmed present and they are ordered from most to least sensitive (*O_1 *to* O_n*, respectively). The grey-filled rectangles in* ***(c)*** *represent the half maximum effective concentration (*EC_{50}*) of species ordered from most to least sensitive.*



(1) (sub)tropical moist broadleaf forest, **(2)** mangroves, **(3)** flooded grassland and savannas, **(4)** desert and xeric shrubland, **(5)** Mediterranean forest, woodland, and scrub, **(6)** temperate broadleaf mixed forest, **(7)** temperate grassland, savanna, and shrublands, **(8)** temperate coniferous forest, **(9)** boreal forest and taiga, and **(10)** tundra and alpine land; EC_{50} based on **(11)** growth, **(12)** reproduction, and **(13)** mortality, total phosphorus for **(14)** cold, **(15)** temperate, and **(16)** xeric lake autotrophs, **(17)** cold and **(18)** temperate lake heterotrophs, **(19)** temperate lake invertebrates, **(20)** (sub)tropical and **(21)** temperate stream autotrophs, **(22)** temperate stream heterotrophs, and **(23)** temperate stream invertebrates; and nitrate (right graph): **(24)** temperate lake invertebrates and **(25)** temperate stream invertebrates. The slope β for 11-13 was converted from the standard deviation σ originally reported in chapter 4 as $\beta = 0.55 \cdot \sigma$.

Test 8.3.1 (two-tailed paired t-test):
H_0: $\alpha_{RSR} = \alpha_{RSA}$ (p value = 0.12)
H_0: $\beta_{RSR} = \beta_{RSA}$ (p value = 0.30)

Test 8.3.2 (Kruskal-Wallis):
H_0: $\beta_{\text{soil pH}} = \beta_{\text{ocean pH}} = \beta_{\text{freshwater TP}} = \beta_{\text{freshwater NO3}}$ (p value = 0.99)

Figure 8.3 *Stressor – response relationships derived for* ***(a)*** *soil and marine water pH and* ***(b)*** *total phosphorus (TP) and NO_3 and* ***(c)*** *β. Coefficients for relative species richness (RSR) – pH soil (chapter 2, filled squares), relative species absence (RSA) – pH (chapter 3, unfilled squares), and pH_{50} – marine water pH (chapter 4, grey squares), RSR – TP (chapter 5, filled triangles), RSA – TP (chapter 6, unfilled triangles), and RSA – TP and NO_3 (chapter 7, grey triangles), respectively.*

8.2.3 Applications LCIA and ERA

The stressor – response relationships were applied into the context of LCIA and ERA because these are two techniques to quantify the impacts of anthropogenic activities on ecosystems. Still, while LCIA quantifies ecosystem damage due to a specific human intervention, e.g. emissions of pollutants due to the manufacture of a certain product (Udo de Haes *et al.*, 2002b), ERA quantifies ecosystem damage due to the concentration of stressors in the environment, irrespective of which human activity may have caused the impact.

In this thesis, the impacts of anthropogenic emissions of TP (estimated via LCIA, chapter 6) and of increased NO_3 and TP levels (estimated with an ERA, chapter 7) were executed on the same scale (i.e., temperate Europe) and for the same freshwater compartments (i.e., lakes and streams). When comparing the two impact assessment approaches, the total impact caused by P emissions in a given year, expressed with a normalization scores (NS), and the ecological risk due to P stress (ER_P) appear to be uncorrelated (Figure 8.4). For example, the Elbe, Danube, Loire, Rhine, and Seine river basins comprise the highest stream-based NS values (above 1E+14 m^3) yet their ER_P values (of 10 to 15%) are similar to the median of ER_P of river basins in 2010 (see TP levels in appendix S7.2.1).

The discrepancy between LCIA and ERA is triggered by how impact scores are derived in each approach. For example, in highly polluted systems where the PNOF is high, the marginal effect model in LCIA gives relatively low impact scores to emissions taking place in considerably polluted systems (since it considers the change in PNOF) yet the ecological risk given to those basins is relatively high (since it includes the cumulative PNOF). Additionally, the characterization factors (CFs) employed in the derivation of NS also include the residence time of P in water (the longest the residence time in the river basin, the highest its CF). Therefore, even though the period that P remains in the water may be long thereby increasing the probability of triggering damage to species, the ecological risk is fairly low if TP concentrations are as well.

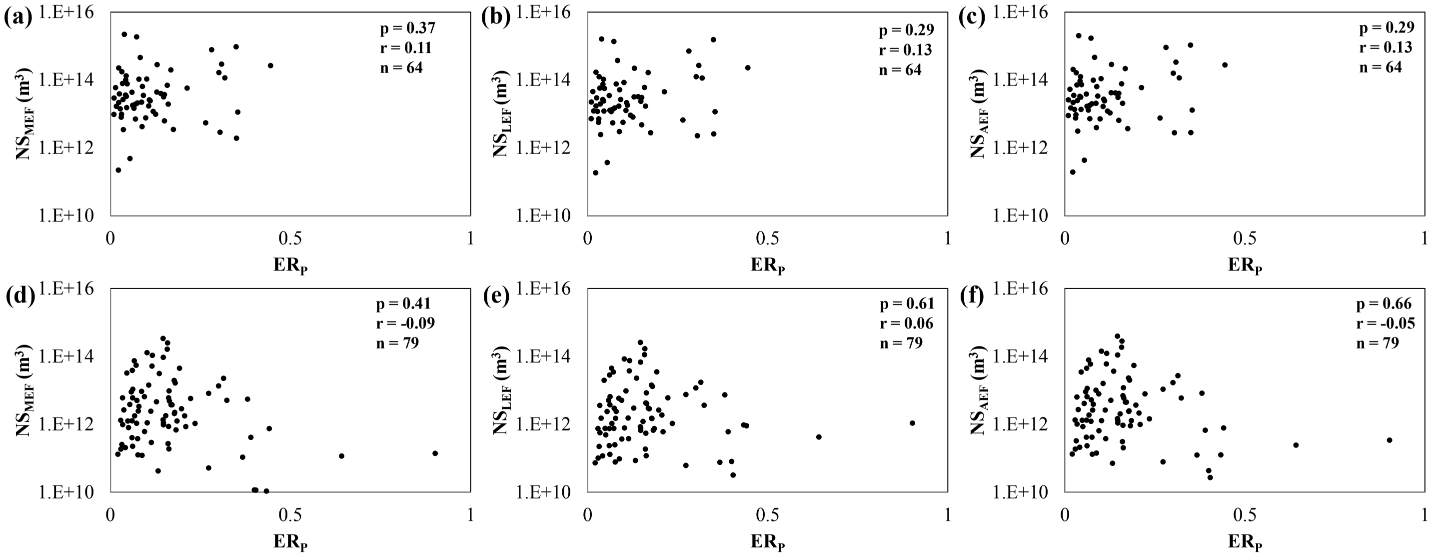


Figure 8.4 *Results of spearman correlations between ecological risk of phosphorus (chapter 7) and normalization scores (NS) of phosphorus emissions based on* ***(a)*** *marginal (MEF),* ***(b)*** *linear (LEF), and* ***(c)*** *average (AEF) effect factors for lakes and* ***(d)*** *marginal (MEF),* ***(e)*** *linear (LEF), and* ***(f)*** *average (AEF) effect factors for streams (chapter 6). P value (p), correlation coefficient (r), and number of samples (n) are shown in top right.*

8.3 Implications and future research recommendations

This thesis developed stressor – response relationships of the impacts of stressor concentrations following important worldwide human interventions today (nutrient causing terrestrial and marine acidification and freshwater eutrophication) on species assemblages. These relationships encompass a large number of species-specific data supplied by a large number of studies performed in different parts of the world. Given that this thesis focuses on stressors that are nutrients and therefore are also essential to the maintenance of organisms, important model choices have been taken, such as the specification of an optimum stressor level beyond which impacts are not accounted for. This thesis provides evidence that inherent spatial variability, the transport of pollutants, and the freshwater type subjected to stress are crucial components to the outcome of impact assessments.

8.3.1 Research novelty

(i) Stressor – response relationships of relative species richness and soil pH and freshwater TP for different biomes and habitats, freshwater types, and species groups (vascular plants, autotrophs, and heterotrophs) were developed. This was attained by gathering a large number of studies and species so as to derive regressions in a similar way, thereby allowing for comparisons with one another.

(ii) In this thesis, novel stressor – response relationships are described for life processes of calcifying species and marine water pH following the development of a large dataset on manipulated pH experiments. Likewise, the employment of these relationships into existing marine acidification scenarios for climate change showed that impacts are highly dependent upon the life process of focus and the pH condition expected in the future.

(iii) The grouping of the stressor – response relationships with models of the transport of pollutants within a LCIA context was performed on larger spatial scales (i.e., global) than those available up to now for terrestrial acidification. Additionally, another important freshwater compartment (i.e., lakes) was included in the derivation of CFs for freshwater eutrophication.

(iv) Still, the comparison of nitrogen and phosphorus impacts has been performed at a broad range of spatial scales and levels of details.

However, up to now, most comparisons were performed for a specific (group of) species or pre-determined stressor levels.

8.3.2 Implications of findings

(v) This thesis provides evidence of long-term species adaptation to the environment they subsist. Furthermore, it estimates the sensitivity of species to changing stressor levels. Past adaptation and current sensitivity are two key components towards assessing the ecological impact of human interventions in the form of pollutant emissions (LCIA) or current stressor levels in the environment (ERA). These components indicate that N-driven eutrophication impacts in freshwater bodies is higher than that of phosphorus and that emission impacts to lakes is higher than that of streams.

(vi) The high variability of emission impacts across river basins confirms the importance of performing impact assessments in a spatially-explicit manner. In this thesis, variability in emission impacts from acidifying and P-driven eutrophying emissions were generally determined by the transport of pollutants and less by their impact they cause to species.

8.3.3 Recommendations for future research

(vii) This thesis does not use mechanistic but probabilistic models to estimate impacts of stressor concentrations on species. For example, high levels of nitrogen and phosphorus affect net primary productivity which, in turn, affects heterotrophic species nutrition and availability of dissolved oxygen. This sequence of events can be better explored so as to allow for the identification, concentration of efforts, and for more options in the control of eutrophication impacts (for example, control of organic matter or secondary consumer populations).

(viii) The impact assessments conducted in this thesis are limited to the estimations of potential losses in relative species richness. Secondary impacts (e.g., hampering of ecosystem services and cascade effects to other species), interactions between organisms (e.g., predator – prey relationships, species competition), interacting effects between stressors (e.g. synergism between eutrophication and acidification), and feedbacks between species and stressors (e.g. escalating effects of marine species losses on climate change) are not taken into account. Although it is nearly impossible to provide a quantitative analysis which includes all possible secondary impacts, interactions, and processes that feed back into the stressor of concern, they can be individually addressed by future research works.

(ix) This thesis estimates additive impacts of phosphorus and nitrogen on freshwater species. The assumption of additive effects, although contested for impacts on net primary productivity, remains to be tested as far as species diversity is concerned.

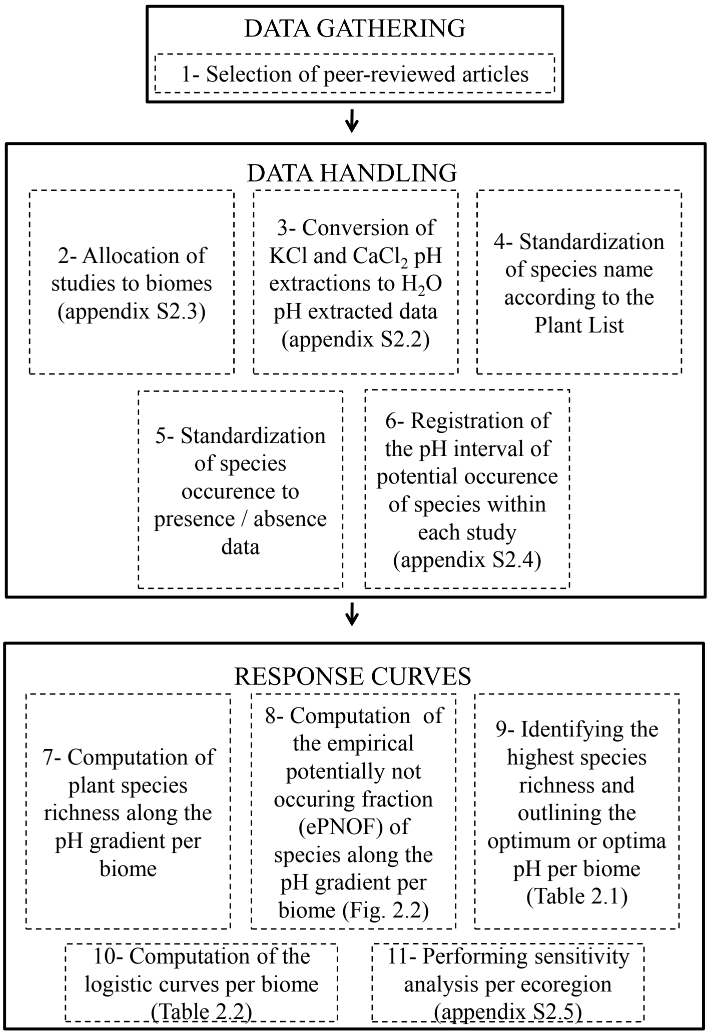
(x) Although the results of this thesis were often attributed to macroevolutionary patterns, such as the long-term favoring of acidophilus plants in inherently low pH soils, microevolutionary events may also influence stressor – response relationships and yet they were not included in this thesis. The influence of short-term evolution should be tested given that it may become more intensive as a result of rapid increasing flow of nutrients.

(xi) In the case of freshwater eutrophication, emission impacts and ecological risks were derived for Europe, for which ample monitoring of stressor levels were available. (Similar efforts elsewhere exist, e.g. GEMStat or the United States Geological Survey databases, but not nearly as intensively). In order for LCA and ERA to be conducted spatially-explicitly with a global coverage, systematic monitoring of stressor concentrations is indispensable. Alternatively, global scale models to predict environmental concentrations can be developed.

(xii) The LCIA effect factors derived for terrestrial acidification were based on marginal changes of the potentially not occurring fraction of vascular plants. Although differences between the marginal, linear, and average effect factors for freshwater eutrophication appear to be less pronounced than the differences triggered by freshwater type, these differences remain to be tested for other impact categories.

SUPPORTING INFORMATION

Appendix S2.1 Description of the methodological steps taken in our study



Appendix S2.2

Appendix S2.2 Conversion coefficients from **(a)** pH – KCl to pH – H_2O and from **(b)** pH – $CaCl_2$ to pH – H_2O and typical pH values per biome.

We used the pH data from the ISRIC-World Soil Information database (Batjes, 2009) to be able to create a regression from pH – KCl and pH – $CaCl_2$ to pH-H_2 (Figure S2.2.1). This conversion was necessary for 15% of the species occurrence ranges, which were distributed in eleven studies of the temperate broadleaf mixed forest biome, four of the temperate grassland, savanna, and shrubland biome, two for (sub)tropical grassland, savanna, and shrubland, and one of the (sub)tropical moist broadleaf mixed forest, boreal forest and taiga, and mediterranean forest, woodland, and scrub biomes. All studies in desert and xeric shrublands reported H_2O-extracted pH so no conversion was necessary in those cases.

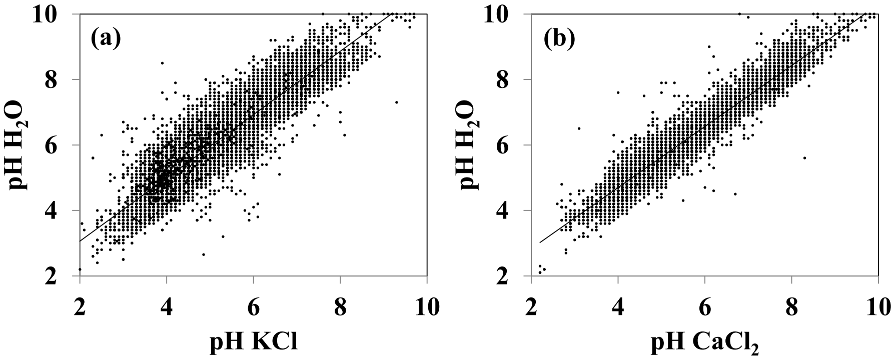


Figure S2.2.1 *Conversion equation to H_2O extracted pH from KCl **(a)** and **(b)** $CaCl_2$ extractions. The red line represents the 95% confidence interval around the dependent variable (mean) for each observation. The equations for pH-KCl and pH-$CaCl_2$ transformation to pH-H_2O are 0.967·pH-KCl+1.127 (R^2=0.843, n = 19,383) and 0.933·pH-$CaCl_2$+0.965 (R^2=0.934, n = 10,883), respectively.*

We used the data from the same database to investigate (1) how soil pH would change along the soil profile (from the topsoil to 1m of depth, Figure S2.2.2) and (2) what are typical soil pH conditions existing today. The data reported by the IRSIC-World Soil Information database (reporting typical soil depths found in the environment) can have a broad range of pH (Figure S2.2.2). For example, pH values commonly found at 50cm of depth in temperate broadleaf mixed forests range from 3.0 to 10.0. However, the mean soil pH shows no clear trend of how pH increases or decreases with depth, suggesting that a 50cm soil depth can be representative of the top 1m of soil profile. The figure also shows what are typical pH conditions per biome. For example, desert and xeric shrublands have a pH value of approximatety 8 while (sub)tropical moist broadleaf forests have a pH value of approximately 5.6 at 50cm of depth.

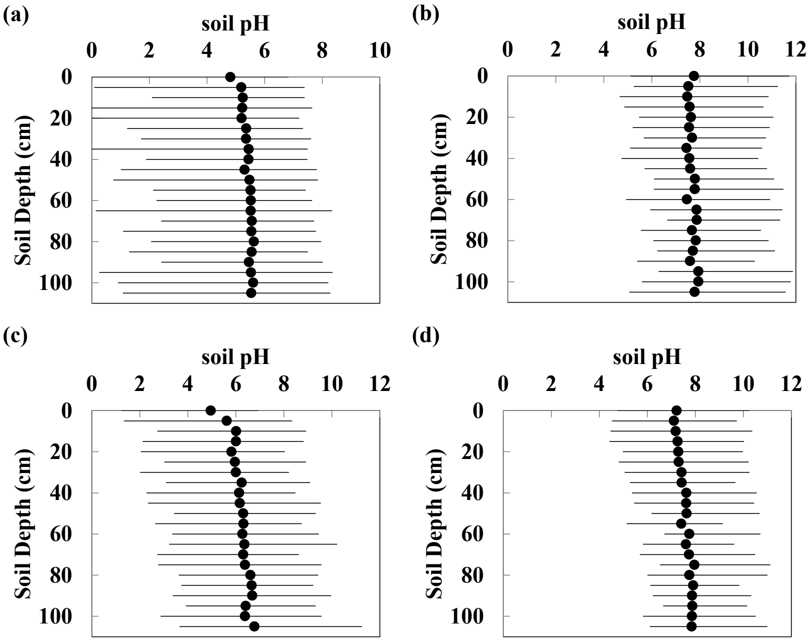


Figure S2.2.2 *Soil pH throughout the soil profile (0 to 100cm of depth) for* ***(a)*** *(sub)tropical moist broadleaf forests,* ***(b)*** *desert and xeric shrubland,* ***(c)*** *temperate broadleaf mixed forest, and* ***(d)*** *temperate grassland, savanna, and shrubland. Dots and error bars are the mean and the minimum and maximum soil pH values that were found in the ISRIC-World Soil Information database (Batjes, 2009).*

Appendix S2.3

Appendix S2.3 List of studies in each biome, the number of species and the pH range of each study.

Table S2.3.1 *Total species per study, the total number of species in the optimum pH ($SR_{opt,j}$), the pH range of species occurrence and the (range of) optimum pH in* ***(a)*** *(sub)tropical moist broadleaf forests,* ***(b)*** *(sub)tropical grassland, savanna, and shrubland,* ***(c)*** *mangrove,* ***(d)*** *(sub)tropical dry broadleaf forests,* ***(e)*** *flooded grassland and savanna,* ***(f)*** *desert and xeric shrubland,* ***(g)*** *mediterranean forest, woodland, and shrubland,* ***(h)*** *temperate broadleaf mixed forest,* ***(i)*** *temperate grassland, savanna, and shrubland,* ***(j)*** *temperate coniferous forest,* ***(k)*** *montane grassland and shrubland,* ***(l)*** *boreal Forest / taiga, and* ***(m)*** *tundra and alpine.*

Study	**Species**	**$SR_{opt,j}$**	**pH range**	**(Range of) pH optimum**
(a) (Sub)tropical moist broadleaf mixed forest				
Banack *et al.* (2002)	22	22	4.8 to 6.9	4.8 to 6.9
Banaticla & Buot (2005)	11	10	4.4 to 7.2	4.9 to 5.0
Chen *et al.* (1997)	50	50	4.1 to 4.7	4.2 to 4.7
Haro-Carrión *et al.* (2009)	14	14	5.9 to 6.4	5.9 to 6.4
Homeier *et al.* (2010)	155	155	3.5 to 5.8	3.8 to 4.3
Hsieh *et al.* (1998)	65	65	3.0 to 5.6	3.7
Ivanauskas *et al.* (2003)	67	67	3.4 to 4.3	3.5 to 3.8
Lesueur *et al.* (1993)	2	2	4.5 to 6.8	4.5 to 6.8
Paoli *et al.* (2006)	8	8	4.2 to 4.5	4.2 to 4.5
Penfold & Lamb (2002)	3	3	4.5 to 7.0	4.5 to 7.0
Poulsen (1996)	30	30	3.7 to 4.6	4.0 to 4.1
Proctor *et al.* (2007)	53	50	4.9 to 5.8	5.3
Siebert (2005)	9	9	4.9 to 7.3	4.9 to 7.3
Teo *et al.* (2003)	6	6	3.9 to 4.4	3.9 to 4.4
Turner *et al.* (1995)	24	24	3.8 to 4.2	3.8 to 4.2
Vetaas (1997)	29	29	6.6 to 8.2	6.6 to 8.2
Zhang *et al.* (2001)	39	39	5.4 to 6.7	6.4 to 6.7
(b) (Sub)tropical grassland, savanna, and shrubland				
Amorim &Batalha (2007)	80	80	4.7 to 5.3	5.0 to 5.1
da Silva &Batalha (2008)	50	50	4.5 to 4.9	4.7
Neto *et al.* (1999)	13	13	4.5 to 6.1	4.5 to 6.1
(c) Mangrove				
Ashton &Macintosh (2002)	12	12	4.1 to 7.2	6.0 to 6.5
Ukpong (1995)	21	21	3.4 to 7.2	4.1 to 5.8
(d) (Sub)tropical dry broadleaf forest				

Study	Species	$SR_{opt,j}$	pH range	(Range of) pH optimum
de Souza *et al.* (2007)	58	58	5.5 to 6.5	5.5 to 6.5
Dubbin *et al.* (2006)	17	12	5.7 to 8.5	7.3 to 8.5
White & Hood (2004)	71	65	6.9 to 7.6	7.0
(e) Flooded grassland and savanna				
Haase (1999)	7	7	5.9 to 6.6	5.9 to 6.6
Ssegawa *et al.* (2004)	11	11	5.3 to 6.9	5.3 to 6.9
(f) Desert and xeric shrubland				
El-Ghani (1998)	25	25	6.6 to 9.4	6.8 to 9.2
Camargo-Ricalde *et al.* (2002)	62	35	5.1 to 7.5	7.4
El-Demerdash *et al.* (1994)	32	32	6.2 to 9.7	7.9 to 8.0
El-Demerdash *et al.* (1995)	31	31	6.2 to 9.7	7.9 to 8.5
Franco-Vizcaíno *et al.* (1993)	27	26	6.0 to 7.7	6.9 to 7.0
Kabir *et al.* (2010)	15	11	5.3 to 9.4	7.0 to 7.1
Li *et al.* (2008)	11	11	7.4 to 7.6	7.4 to 7.6
Mahmood *et al.* (1994)	15	9	7.7 to 9.8	7.7 to 7.9
Parker (1991)	13	13	6.6 to 8.7	7.2 to 8.0
Pettit & Naiman (2007)	107	107	7.0 to 8.0	7.0 to 8.0
Shaltout *et al.* (1997)	53	52	7.1 to 8.3	7.5 to 7.6
Titus *et al.* (2002)	3	3	7.8 to 8.8	8.1 to 8.5
Toft & Elliot-Fisk (2002)	2	2	9.6 to 9.7	9.6 to 9.7
Walker *et al.* (2001)	2	2	7.6 to 7.9	7.6 to 7.9
Zhang *et al.* (2005)	18	17	6.1 to 10.4	7.4 to 7.8
(g) Mediterranean Forest, Woodland, and Shrubland				
Navas *et al.* (2008)	8	8	6.4 to 8.6	7.4 to 8.5
Richards *et al.* (1997)	14	9	4.9 to 6.2	5.4 to 5.5
Römermann *et al.* (2005)	6	6	6.4 to 6.7	6.5 to 6.7
Ruecker *et al.* (1998)	3	3	8.0 to 8.3	8.0 to 8.3
(h) Temperate broadleaf mixed forest				
Abrams & Hayes (2008)	12	12	4.3 to 4.9	4.3 to 4.9
Ahokas (1997)	5	5	3.6 to 6.0	4.1 to 5.4
Akbar *et al.* (2009)	3	3	7.1 to 8.1	7.5
Andersson (1992)	19	19	3.2 to 5.0	3.2 to 5.0
Arii & Lechowicz (2002)	10	10	4.1 to 5.9	4.1 to 5.9

Appendix S2.3

Study	Species	$SR_{opt,j}$	pH range	(Range of) pH optimum
Baeten *et al.* (2009)	87	87	3.1 to 6.3	3.7 to 5.5
Bellemare *et al.* (2005)	89	89	4.7 to 5.1	4.7 to 5.1
Bernard & Seischab (1995)	16	14	3.4 to 4.1	3.5 to 4.0
Bigelow & Canham (2002)	6	6	3.4 to 7.1	4.3 to 6.1
Bjørnstad (1991)	31	31	4.0 to 5.3	4.0 to 5.3
Brosofske *et al.* (2001)	11	11	3.6 to 4.8	4.4
Brunet *et al.* (1996)	79	74	3.9 to 5.0	4.6
Brunet *et al.* (1997a)	104	104	4.5 to 5.1	4.7
Brunet *et al.* (1997b)	43	43	4.6 to 5.5	5.1 to 5.3
Chapman &Bannister (1995)	16	16	4.0 to 5.5	4.0 to 5.5
Cole & Weltzin (2004)	21	13	5.3 to 6.1	5.3 to 5.5
Coudun &Gégout (2007)	56	56	3.0 to 8.5	3.0 to 8.5
Coudun *et al.* (2006)	11	11	6.5 to 7.5	6.5 to 7.5
Dambrine *et al.* (2007)	35	35	4.8 to 5.1	4.8 to 5.1
De Graaf *et al.* (2009)	109	109	3.8 to 6.4	4.7 to 4.9
Dick & Gilliam (2007)	31	31	3.9 to 4.4	3.7 to 4.4
Diekmann & Lawesson (1999)	4	4	4.0 to 8.9	4.5 to 8.4
Dzwonko (2001)	40	19	4.0 to 5.8	4.5
Emerson *et al.* (2009)	11	11	4.5 to 8.2	4.5 to 8.2
Falkengren-Grerup *et al.* (1998)	4	4	4.8 to 5.1	4.8 to 5.1
Fennema (1992)	72	72	2.8 to 5.6	3.1 to 5.4
Gillian & Turrill (1993)	9	9	4.2 to 4.3	4.2 to 4.3
Graae (2000)	15	15	4.1 to 5.0	4.2 to 4.4
Graae *et al.* (2003)	27	27	3.3 to 6.3	3.4 to 5.5
Härdtle *et al.* (2005)	22	22	2.4 to 8.0	3.3 to 4.1
Hofmeister *et al.* (2009)	134	111	3.3 to 7.7	4.1 to 4.2
Hutchinston *et al.* (1999)	82	82	3.8 to 4.5	4.2
Jacob *et al.* (2009)	6	6	4.5 to 6.4	6.2 to 6.4
Kooijman (2010)	44	44	4.3 to 8.7	5.5 to 6.8
Lang *et al.* (2009)	21	13	4.0 to 7.9	4.6 to 4.7
Lukešová & Hoffmann (1996)	19	17	3.5 to 6.2	5.8 to 6.0
Petersen (1994)	57	37	4.7 to 8.0	6.0 to 6.5
Piernik (2005)	69	69	3.4 to 9.4	6.7 to 8.3
Plue *et al.* (2008)	38	38	3.3 to 8.4	5.2 to 7.0
Plue *et al.* (2009)	48	48	4.7 to 5.2	4.7 to 5.2
Roberts & Gilliam (1995)	27	18	4.4 to 5.6	4.4 to 4.6
Sage *et al.* (2005)	52	52	5.1 to 6.6	5.8 to 5.9

Study	Species	$SR_{opt,j}$	pH range	(Range of) pH optimum
Skousen *et al.* (1994)	10	10	3.3 to 6.9	4.3 to 5.2
Tyler (1996)	60	43	4.2 to 7.2	4.6 to 5.0
Van Couwenberghe *et al.* (2010)	8	8	3.8 to 7.9	3.8 to 7.9
Van Rossum *et al.* (1999)	43	43	3.8 to 8.0	3.8 to 8.0
Verheyen & Hermy (2001)	14	14	5.5 to 6.4	5.5 to 6.4
Vetaas (2000)	36	36	4.0 to 7.5	4.0 to 7.5
Ware *et al.* (1992)	21	21	4.5 to 8.0	6.6 to 7.8
West *et al.* (2009)	6	6	6.1 to 6.6	6.3 to 6.4
Xu & Inubushi (2009)	9	9	4.9 to 5.7	4.9 to 5.7
Zas & Alonso (2002)	19	19	4.2 to 5.6	4.8 to 4.9
(i) Temperate grassland, savanna, and shrubland				
Baasch *et al.* (2009)	3	3	2.6 to 7.9	3.2 to 7.6
Beumer *et al.* (2008)	26	26	4.6 to 6.2	4.6 to 6.2
Dollar *et al.* (1992)	15	14	4.9 to 6.4	5.4 to 5.5
Heikens & Robertson (1995)	94	68	4.1 to 8.1	7.6
Mårtensson & Olsson (2010)	3	3	4.6 to 9.1	5.9 to 9.1
Olsson *et al.* (2009)	25	25	4.5 to 9.1	4.5 to 9.1
Reinhammar *et al.* (2002)	75	75	4.4 to 5.8	4.4 to 5.8
Rodríguez *et al.* (1995)	45	42	5.0 to 6.7	6.2
Roem & Berendse (2000)	28	12	4.0 to 8.1	5.2 to 5.3
Sebastiá (2004)	13	5	5.4 to 7.4	5.4 to 6.0
Spiegelberger *et al.* (2006)	12	12	5.0 to 5.1	5.0 to 5.1
Stevens *et al.* (2010)	40	40	3.3 to 5.7	3.3 to 5.7
Tyler (2000)	63	63	4.5 to 8.7	6.1 to 7.2
Wagner (2009)	63	63	5.0 to 7.0	5.0 to 7.0
Walker *et al.* (2004)	33	33	4.3 to 6.1	5.4
Zuo *et al.* (2009)	25	25	7.0 to 7.6	7.3 to 7.5
(j) Temperate Coniferous Forest				
Dimopoulos *et al.* (1996)	29	24	4.5 to 8.3	7.4
Goldin (2001)	6	6	6.4 to 8.2	7.0
Hülber *et al.* (2008)	105	105	3.3 to 7.8	3.6 to 7.5
Johnston & Johnston (2004)	31	28	4.6 to 6.5	4.6 to 4.8
Kutnar & Martinčič (2003)	58	55	3.1 to 6.7	4.7 to 6.1
Nygaard & Abrahamsen (1991)	7	7	3.7 to 3.8	3.7 to 3.8
Nygaard & Ødegaard (1999)	22	22	3.3 to 5.3	3.3 to 4.5

Appendix S2.3

Study	Species	$SR_{opt,j}$	pH range	(Range of) pH optimum
Totland & Nylehn (1998)	16	16	4.1 to 5.6	4.1 to 5.6
(k) Montane grassland and shrubland				
Baniya *et al.* (2009)	135	135	6.0 to 7.0	6.0 to 7.0
Yimer *et al.* (2006)	4	4	5.5 to 6.2	5.5 to 6.0
(l) Boreal Forest / Taiga				
Elgersma & Dhillion (2002)	50	50	3.2 to 6.1	4.4
Giesler *et al.* (1998)	14	13	4.1 to 6.4	4.1 to 5.4
Karim & Mallik (2008)	33	33	5.3 to 6.9	6.9
Koptsik *et al.* (2001)	16	16	4.9 to 7.7	5.1 to 5.2
(m) Tundra and alpine				
Arnesen *et al.* (2007)	41	36	4.6 to 7.7	7.0 to 7.7
Auerbach *et al.* (1997)	5	5	4.0 to 7.3	4.0 to 7.3
Austrheim *et al.* (2005)	53	53	4.4 to 4.5	4.4 to 4.5
Razzhivin (1994)	73	72	4.5 to 7.9	6.0 to 6.4
Walker (2000)	6	6	5.3 to 7.0	5.3 to 7.0
Walker & Everett (1991)	34	30	6.9 to 7.7	7.3

Appendix S2.4 Species-specific data

Table S2.4.1 lists the number of species within each plant family within each biome. Table S2.4.2 lists the species occurring in each biome and their pH range of occurrence. Occasional records consist of genus or lower taxonomic ranks. The species, genus, or status in the Plant List database is either "accepted", "unresolved", or "genus" (in the case of genus records).

Table S2.4.1 *Number of species in each family of vascular plants within each biome*

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest / Taiga	Tundra and alpine	Total
Acanthaceae	4		3			6		1						14
Achariaceae	1													1
Actinidiaceae	1													1
Adiantaceae	1							1						2
Adoxaceae	1							6						7
Altingiaceae								1						1
Alzateaceae	1													1
Amaranthaceae	1	1	2			31		8	6		5			54
Amaryllidaceae								2	2		1			5
Anacardiaceae	5	2		3		2		1	3					16
Annonaceae	11	3		2										16
Apiaceae	3					3		12	13	6	4	1		42
Apocynaceae	4	2		2		7		2	1	1				19
Aquifoliaceae	14							1						15
Araceae	15							3			1			19
Araliaceae	5							4	1	1	1			12
Arecaceae	11	3	3	2		2								21
Aristolochiaceae								3		1				4
Asparagaceae						12		15	3	5	1	4	1	41
Aspleniaceae	1							2		1				4
Atherospermataceae	1													1
Balsaminaceae								2						2

Appendix S2.4

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest / Taiga	Tundra and alpine	Total
Begoniaceae	1													1
Berberidaceae	1							1			1			3
Betulaceae								13	3	2		6	1	25
Bignoniaceae	2	3		5		1								11
Bonnetiaceae	1													1
Boraginaceae	1			4		9		6	4	3	2		1	30
Brassicaceae	1					4		11	2	3	6		5	32
Bromeliaceae	2					1								3
Burseraceae	3			3		1								7
Cactaceae						20								20
Campanulaceae								7	5	1	2		2	17
Cannabaceae		1		1		1		1	1		1			6
Capparaceae						1								1
Caprifoliaceae	1							9	2	7	5	1	1	26
Caryophyllaceae						1		16	15	4	2		12	50
Celastraceae	4	1		2	1	1		2	1	1			2	15
Chloranthaceae	2													2
Chrysobalanaceae	5													5
Cistaceae								1	3					4
Cleomaceae						3								3
Clethraceae	2													2
Clusiaceae	6													6
Combretaceae			1	1		7								9
Commelinaceae						1		1						2
Compositae	15	8	1	1		37	5	57	55	23	18	9	20	249
Connaraceae	1	1												2
Convolvulaceae	1					3		2	2		2			10
Cornaceae								5	2	1				8
Crassulaceae								2	2				1	5
Cucurbitaceae						3								3

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest / Taiga	Tundra and alpine	Total
Cunoniaceae	7													7
Cupressaceae							1	2	2	1	1	1		8
Cyatheaceae	5													5
Cyperaceae	5	2			11	5		48	29	20	1	1	20	142
Daphniphyllaceae	1													1
Davalliaceae	1													1
Dennstaedtiaceae	1							2	1	1				5
Diapensiaceae									1				2	3
Dioscoreaceae								1						1
Dipterocarpaceae	8													8
Droseraceae		1						2	1					4
Dryopteridaceae	1							7		4		2		14
Ebenaceae	4	1		2		3		1						11
Elaeocarpaceae	4													4
Ephedraceae						1					1			2
Equisetaceae								2	2	2	1	1	2	10
Ericaceae	6	1					2	13	10	9	2	13	14	70
Escalloniaceae	1													1
Euphorbiaceae	13	3		6		7		4	3	3				39
Fagaceae	13			1			1	18	7	2				42
Fouquieriaceae						2								2
Gentianaceae	1	1						2	6	1	5		2	18
Geraniaceae						2		4	3	1	2	1	1	14
Gesneriaceae	1													1
Gleicheniaceae	1													1
Grossulariaceae								4		1				5
Hamamelidaceae								1						1
Humiriaceae	1													1
Hydrangeaceae	1							1						2
Hymenophyllaceae	3													3

Appendix S2.4

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest / Taiga	Tundra and alpine	Total
Hypericaceae	2							6	3	2	1			14
Hypoxidaceae	1	1												2
Iridaceae		1							1			1		3
Iteaceae	1													1
Ixioliriaceae									1					1
Ixonanthaceae	1													1
Juglandaceae	1							6	4					11
Juncaceae						1		16	10	8	1	1	5	42
Juncaginaceae								1						1
Krameriaceae						2								2
Lacistemataceae	1													1
Lamiaceae	4	5		2	1	2		16	16	6	7			59
Lauraceae	30			1		1		2						34
Lecythidaceae	2													2
Leguminosae	21	22	2	30		45	2	31	30	5	10	2	6	206
Lentibulariaceae									1	1			1	3
Liliaceae								3		2	1		1	7
Limeaceae						1								1
Linaceae							1	1						2
Linderniaceae	1													1
Loranthaceae	1													1
Lycopodiaceae	1	1						2		2		2	1	9
Lythraceae	1	2	1					1						5
Magnoliaceae	2							1						3
Malpighiaceae	2	2		2										6
Malvaceae	5	6	1	4	1	16		3	1		1			38
Marantaceae	1													1
Melanthiaceae								3		2				5
Melastomataceae	23	2			1									26
Meliaceae	3			7	1	1								12

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest / Taiga	Tundra and alpine	Total
Melianthaceae	1													1
Menispermaceae	1					1								2
Molluginaceae						1								1
Montiaceae								2						2
Moraceae	13			3				1						17
Myricaceae	1													1
Myristicaceae	2													2
Myrtaceae	14	13		9						1				37
Nartheciaceae								1						1
Nepenthaceae	2													2
Nitrariaceae						2								2
Nyctaginaceae	2			1										3
Ochnaceae	2	3				1								6
Olacaceae	7													7
Oleaceae	5					2		4	2	2				15
Onagraceae						1		5	1	1		1	2	11
Ophioglossaceae								1	1					2
Orchidaceae	1							6	1	6	3	1		18
Orobanchaceae						2		8	12	3	2	2	10	39
Oxalidaceae	2							3		1		1		7
Pandaceae	1													1
Papaveraceae	1					1		4		1	1		1	9
Pedaliaceae						1								1
Pentaphylacaceae	10													10
Peraceae	2													2
Phrymaceae	1													1
Phyllanthaceae	6	1		2		3				1				13
Pinaceae				2			1	9		7	1	5		25
Piperaceae	4													4
Pittosporaceae	1													1

Appendix S2.4

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest / Taiga	Tundra and alpine	Total
Plantaginaceae	2					2		8	10	3	1	2	2	30
Platanaceae								1	1	1				3
Plumbaginaceae						1								1
Poaceae	10	18				40	4	72	67	23	17	6	13	270
Podocarpaceae	3													3
Polygalaceae								2	3	2				7
Polygonaceae				4	1	4		14	4	1	6		5	39
Polypodiaceae	3							1						4
Primulaceae	7			2				7	2	1	1	2	1	23
Proteaceae	2	1					7			1				11
Putranjivaceae	3			1										4
Ranunculaceae	2							17	11	8	5	4	9	56
Resedaceae						2								2
Rhamnaceae	1	1		5		1		2	1					11
Rosaceae	7							39	16	13	9	9	12	105
Rubiaceae	32	2		9		7		14	8	7	2	1		82
Rutaceae	2			1				1						4
Sabiaceae	2													2
Salicaceae	1	1		5		1	2	7	7	1		4	6	35
Salvadoraceae						1								1
Santalaceae	1													1
Sapindaceae	5	1		4		2		11	3	1		1		28
Sapotaceae	8	3		4										15
Sarcobataceae						1								1
Saxifragaceae								4	1				5	10
Schisandraceae	2													2
Schlegeliaceae	1													1
Scrophulariaceae						2		3		1	1			7
Selaginellaceae	1								1					2
Simaroubaceae	1													1

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest / Taiga	Tundra and alpine	Total
Simmondsiaceae						1								1
Siparunaceae	3													3
Smilacaceae	1							2	1					4
Solanaceae	3	1				5		3						12
Staphyleaceae	2													2
Styracaceae	3													3
Symplocaceae	6													6
Tamaricaceae						5								5
Theaceae	4													4
Thelypteridaceae	2							1		2		2		7
Thymelaeaceae								1		2	1			4
Tofieldiaceae									1				2	3
Trochodendraceae	1													1
Typhaceae									1					1
Ulmaceae								4	2	1				7
Urticaceae	6			2				3						11
Verbenaceae		1		1		4								6
Violaceae	3			1				12	5	2	1	1	3	28
Vitaceae						2		2	1					5
Vochysiaceae	1	2			1									4
Winteraceae	1													1
Woodsiaceae	2							5		3		2		12
Xanthorrhoeaceae	1													1
Zingiberaceae	6													6
Zygophyllaceae						9								9
Total	531	124	14	137	18	351	26	682	421	229	137	90	172	2932

Appendix S2.4

Table 2.4.2 *List of species and their respective pH range of occurrence found in* ***(a)*** *Tropical and subtropical moist broadleaf forest,* ***(b)*** *Tropical and subtropical grassland, savanna, and shrubland,* ***(c)*** *Mangrove,* ***(d)*** *Tropical and subtropical dry broadleaf forest,* ***(e)*** *Flooded grassland and savanna,* ***(f)*** *Desert and xeric shrublands,* ***(g)*** *Mediterranean Forest, Woodland, and Shrubland,* ***(h)*** *Temperate broadleaf mixef forest,* ***(i)*** *Temperate Grassland, Savanna, and Shrubland,* ***(j)*** *Temperate Coniferous Forest,* ***(k)*** *Montane grassland and shrubland,* ***(l)*** *Boreal Forest / Taiga, and* ***(m)*** *Tundra and alpine.*

Species	**pH range**
(a) Tropical and Subtropical Moist Broadleaf Forest	
Abarema killipii (Britton & Killip) Barneby & J.	3.7 to 4.3
Acacia mangium Willd.	4.5 to 6.8
Acalypha australis L.	6.4 to 6.7
Acer caudatifolium Hayata	3 to 3.7
Acer negundo subsp. mexicanum (DC.) Wesm.	3.1 to 5.6
Actinodaphne mushaensis (Hayata) Hayata	3 to 3.7
Adinandra dumosa Jack	3.9 to 4.4
Adinandra formosana Hayata	3 to 4.7
Aechmea angustifolia Poepp. & Endl.	5.9 to 6.4
Ageratum conyzoides (L.) L.	6.4 to 6.7
Aidia cochinchinensis Lour.	3.6 to 5.6
Alchornea grandiflora Müll.Arg.	3.7 to 5.8
Alchornea triplinervia (Spreng.) Müll.Arg.	3.7 to 4.4
Alchorneopsis floribunda (Benth.) Müll.Arg.	3.8 to 5.8
Alibertia edulis (Rich.) A.Rich. ex DC.	3.4 to 4.3
Alniphyllum pterospermum Matsum.	4.1 to 4.7
Alocasia peltata M.Hotta	3.7 to 4.1
Alzatea verticillata Ruiz & Pav.	3.7 to 4.3
Amaranthus spinosus L.	6.4 to 6.7
Amomum coriaceum R.M.Sm.	3.7 to 4.1
Amydrium medium (Zoll. & Moritzi) Nicolson	3.7 to 4.6
Aniba muca (Ruiz & Pav.) Mez	3.8 to 5.8
Anisomeles indica (L.) Kuntze	6.4 to 6.7
Annickia chlorantha (Oliv.) Setten & Maas	5.1 to 5.4
Annona andicola (Maas & Westra) H.Rainer	3.8 to 5.8
Anthurium asplundii Croat	5.9 to 6.4
Anthurium dolichostachyum Sodiro	5.9 to 6.4
Anthurium obtusum (Engl.) Grayum	5.9 to 6.4
Antiaris sp.	5.3 to 5.4
Antidesma japonicum var. japonicum	4.1 to 4.7
Antidesma laciniatum Müll.Arg.	4.9 to 5.3
Antrocaryon klaineanum Pierre	4.9 to 5.3
Aparisthmium cordatum (A.Juss.) Baill.	3.4 to 4.3
Apostasia wallichii R.Br.	3.7 to 4.1
Archidendron lucidum (Benth.) I.C.Nielsen	4.1 to 4.7
Ardisia quinquegona Blume	4.1 to 4.7
Ardisia sieboldii Miq.	3 to 5.6
Aspidosperma discolor A.DC.	3.4 to 4.3
Asplenium cymbifolium Christ#	4.7 to 5.2
Astronia ferruginea Elmer	4.1 to 4.7
Begonia sp.	3.7 to 4.6
Beilschmiedia erythrophloia Hayata	3.7 to 5.6
Beilschmiedia tovarensis (Klotzsch & H.Karst. ex Meisn.) Sachiko Nishida	3.7 to 4.4
Beilschmiedia tsangii Merr.	4.1 to 4.7
Bejaria aestuans Mutis ex L.	3.7 to 4.4
Bellucia grossularioides (L.) Triana	3.4 to 4.3
Berberis asiatica Roxb. ex DC.	6.6 to 8.2
Berlinia bracteosa Benth.	4.9 to 5.4
Bersama abyssinica Fresen.	5.4 to 5.7
Bidens biternata (Lour.) Merr. & Sherff	6.4 to 6.7
Boesenbergia flavoalba R.M.Sm.	3.7 to 4.6
Bothriospermum zeylanicum (J.Jacq.) Druce	6.4 to 6.7
Brachiaria eruciformis (Sm.) Griseb.	6.4 to 6.7
Bridelia micrantha (Hochst.) Baill.	5.1 to 5.3
Byrsonima crispa A.Juss.	3.4 to 4.3
Byrsonima homeieri W.R.Anderson	3.8 to 5.8
Calamus didymocarpus Warb. ex Becc.	4.9 to 7.3
Calamus leiocaulis Becc. ex K.Heyne	4.9 to 7.3
Calamus leptostachys Becc. ex K.Heyne	4.9 to 7.3

Species	pH range
Calamus minahassae Warb. ex Becc.	4.9 to 7.3
Calamus ornatus Blume	4.9 to 7.3
Calamus symphysipus Mart.	4.9 to 7.3
Calamus zollingeri Becc.	4.9 to 7.3
Calyptranthes concinna DC.	3.8 to 5.8
Calyptranthes pulchella DC.	3.5 to 4.3
Campomanesia sp.	3.5 to 3.8
Capillipedium parviflorum (R.Br.) Stapf	5.4 to 6.7
Carex vesiculosa Boott	6.6 to 8.2
Casearia stipitata Mast. #	5.1 to 5.3
Cassytha filiformis L.	3.8 to 4.2
Castanopsis carlesii (Hemsl.) Hayata	3 to 5.6
Castanopsis faberi Hance	4.1 to 4.7
Castanopsis indica (Roxb. ex Lindl.) A.DC.	6.6 to 8.2
Castanopsis tribuloides (Sm.) A.DC.	6.6 to 8.2
Cecropia andina Cuatrec.	3.8 to 5.8
Cecropia angustifolia Trécul	3.8 to 5.8
Cecropia distachya Huber	3.5 to 4.3
Ceiba speciosa (A.St.-Hil.) Ravenna	3.7 to 4.3
Centella asiatica (L.) Urb.	5.4 to 6.7
Cephalomanes apiifolium (C. Presl) K. Iwats.	4.4 to 5
Cerasus campanulata (Maxim.) A.N. Vassiljeva	3 to 4.1
Cestrum schlechtendahlii G.Don	3.5 to 5.8
Chaetocarpus echinocarpus (Baill.) Ducke	3.4 to 4.3
Cheiloclinium cognatum (Miers) A.C.Sm.	3.4 to 4.3
Chromolaena odorata (L.) R.M.King & H.Rob.	6.6 to 8.2
Chrysophyllum lanatum T.D.Penn.	3.5 to 5.8
Cinchona hirsuta Ruiz & Pav.	3.5 to 4.3
Cinnamomum camphora (L.) J.Presl	3 to 4.1
Cinnamomum subavenium Miq.	3 to 4.1
Cissampelos pareira L.	6.6 to 8.2
Clematis montana Buch.-Ham. ex DC.	6.6 to 8.2
Clethra revoluta (Ruiz & Pav.) Spreng.	3.7 to 4.3
Cleyera japonica Thunb.	3.1 to 5.6
Clinopodium piperitum (D.Don) Murata	6.6 to 8.2
Clusia ducu	3.7 to 4.3
Clusia ducuoides Benth.	3.7 to 4.3
Coffea liberica Hiern	5.1 to 5.5
Cola praeacuta Brenan & Keay	5.1 to 5.3
Cola verticillata (Thonn.) Stapf ex A.Chev.	5.1 to 5.3
Colquhounia coccinea Wall.	6.6 to 8.2
Connarus perrottetii (DC.) Planch.	3.4 to 4.3
Conyza canadensis (L.) Cronquist	6.4 to 6.7
Copaifera langsdorffii Desf.	3.4 to 4.3
Corydalis chaerophylla DC.	6.6 to 8.2
Couepia recurva Spruce ex Prance	3.8 to 5.8
Critoniopsis floribunda (Kunth) H.Rob.	3.8 to 5.8
Critoniopsis zamorensis X. Haro & H.Rob.	3.8 to 5.8
Cupania scrobiculata Rich.	3.4 to 4.3
Cuscuta reflexa Roxb.	6.6 to 8.2
Cyathea callosa H. Christ#	4.4 to 5.3
Cyathea contaminans (Wall. ex Hook.) Copel.	4.8 to 7.1
Cyathea lepifera (J. Sm. ex Hook.) Copel.	3.7 to 5.6
Cyathea loheri H. Christ	4.7 to 5.7
Cyathea philippinensis Baker#	4.4 to 5.2
Cynodon dactylon (L.) Pers.	6.4 to 6.7
Cyrtandra phoenicolasia Lauterb.	3.7 to 4.1
Dacryodes nitens Cuatrec.	3.4 to 4.3
Daemonorops robusta Warb. ex Becc.	4.9 to 7.3
Daphniphyllum pentandrum Hayata	3.1 to 5.6
Dasylepis racemosa Oliv. #	5.1 to 5.4
Decaspermum gracilentum (Hance) Merr. & L.M.Perry	4.1 to 4.7
Dendropanax dentiger (Harms) Merr.	3 to 4.1
Dendrophthoe pentandra (L.) Miq.	3.8 to 4.2
Desmodium multiflorum DC.	6.6 to 8.2
Dianella ensifolia (L.) DC.	3.8 to 4.2
Dichostemma glaucescens Pierre	5.1 to 5.3
Dicranopteris linearis (Burm. f.) Underw.	3.8 to 5.5
Dictyocaryum lamarckianum (Mart.) H.Wendl.	3.7 to 4.3
Digitaria sanguinalis (L.) Scop.	6.4 to 6.7
Dioicodendron dioicum (K.Schum. & K.Krause) Steyerm.	3.5 to 4.3
Diospyros eriantha Champ. ex Benth.	4.1 to 4.7

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Species	pH range
Diospyros gabunensis Gürke	5.1 to 5.3
Diospyros morrisiana Hance	3 to 4.1
Diospyros zenkeri (Gürke) F.White	5.3 to 5.4
Diplazium crenato-serratum T. Moore[#]	3.7 to 4.1
Diplazium riparium Holttum[#]	4 to 4.6
Diplospora dubia (Lindl.) Masam.	3 to 5.6
Diplotropis triloba Gleason	3.4 to 4.3
Dipsacus inermis Wall.	6.6 to 8.2
Dipterocarpus sublamellatus Foxw.	4.2 to 4.5
Doryphora sassafras Endl.	4.5 to 7
Drimys granadensis L.f.	3.5 to 4.4
Drypetes bipindensis (Pax) Hutch.	5.1 to 5.3
Drypetes paxii Hutch.	5.3 to 5.4
Drypetes staudtii (Pax) Hutch.	4.9 to 5.3
Duchesnea indica (Andrews) Focke	6.4 to 6.7
Dulacia inopiflora (Miers) Kuntze	3.4 to 4.3
Dussia sp.	3.8 to 5.8
Elaeagia obovata Rusby	3.5 to 4.4
Elaeagia pastoensis L.E.Mora	3.5 to 4.4
Elaeocarpus japonicus Siebold	3 to 4.1
Elaeocarpus sylvestris (Lour.) Poir.	4.1 to 4.7
Elettariopsis kerbyi R.M.Sm.	3.7 to 4.6
Elettariopsis stenosiphon (K.Schum.) B.L.Burtt & R.M.Sm.	4 to 4.1
Emilia sonchifolia (L.) DC. ex DC.	6.4 to 6.7
Endlicheria griseosericea Chanderb.	3.8 to 5.8
Endlicheria oreocola Chanderb.	3.7 to 4.4
Engelhardtia roxburghiana Lindl.	3 to 5.6
Epipremnum falcifolium Engl.	3.7 to 4.1
Eriachne pallescens R.Br.	3.8 to 4.2
Erigeron annuus (L.) Pers.	6.4 to 6.7
Eschweilera sessilis A.C.Sm.	3.5 to 4.3
Eugenia egensis DC.	3.8 to 5.8
Euonymus laxiflorus Champ. ex Benth.	3 to 4.1
Eurya hayatae Yamam.	4.1 to 4.7
Eurya loquaiana Dunn	3 to 5.6
Euterpe precatoria Mart.	3.7 to 4.3
Evodia merrillii Kaneh. & Sasaki[#]	4.1 to 4.7
Faidherbia albida (Delile) A.Chev.	4.5 to 6.8
Faramea bangii Rusby	3.8 to 5.8
Faramea coerulescens K.Schum. & K.Krause	3.5 to 4.4
Faramea glandulosa Poepp.	3.8 to 5.8
Faramea uniflora Dwyer & M.V.Hayden	3.8 to 5.8
Fatoua pilosa Gaudich.	6.4 to 6.7
Ficus citrifolia Mill.	3.8 to 5.8
Ficus cuatrecasasiana Dugand	3.8 to 5.8
Ficus fistulosa Reinw. ex Blume	4.1 to 4.7
Ficus insipida Willd.	4.8 to 6.9
Ficus mucuso Welw. ex Ficalho	5.3 to 5.4
Ficus tonduzii Standl.	3.8 to 5.8
Frangula granulosa (Ruiz & Pav.) Grubov	3.5 to 4.3
Fraxinus griffithii C.B.Clarke	3 to 4.1
Freziera campanulata A.L. Weitzman[#]	3.5 to 4.4
Freziera karsteniana (Szyszyl.) Kobuski	3.5 to 4.4
Garcinia mannii Oliv.	4.9 to 5.4
Garcinia multiflora Champ. ex Benth.	4.1 to 4.7
Gaultheria reticulata Kunth	3.7 to 4.4
Geissanthus vanderwerffii Pipoly	3.5 to 4.3
Glochidion rubrum Blume	3.7 to 5.6
Gloeospermum sp.	3.5 to 5.8
Gnaphalium polycaulon Pers.	6.4 to 6.7
Gordonia axillaris (Roxb. ex Ker) Endl.	3 to 4.7
Graffenrieda emarginata (Ruiz & Pav.) Triana	3.8 to 5.8
Graffenrieda harlingii Wurdack	3.5 to 4.3
Guapira sp.	3.8 to 5.8
Guarea kunthiana A.Juss.	3.8 to 5.8
Guatteria blepharophylla Mart.	3.4 to 4.3
Guatteria foliosa Benth.	3.4 to 4.3
Guatteria schomburgkiana Mart.	3.4 to 4.3
Guzmania monostachia (L.) Rusby ex Mez	5.9 to 6.4
Handroanthus chrysanthus (Jacq.) S.O.Grose	3.8 to 5.8
Hedyosmum anisodorum Todzia	3.7 to 4.3
Hedyosmum translucidum Cuatrec.	3.7 to 4.3
Heisteria sp.	3.8 to 5.8

Species	pH range
Helicia formosana Hemsl.	3 to 5.6
Helicostylis tovarensis (Klotzsch & H.Karst.) C.C.Berg	3.8 to 5.8
Heliocarpus americanus L.	3.5 to 5.8
Himatanthus sucuuba (Spruce ex Müll.Arg.) Woodson	3.4 to 4.3
Hirtella bullata Benth.	3.4 to 4.3
Hirtella racemosa Lam.	3.4 to 4.3
Homalomena ovata Engl.	3.7 to 4.1
Hopea ferruginea Parijs[#]	4.2 to 4.5
Hoya diversifolia Blume[#]	3.8 to 4.2
Hydrangea chinensis Maxim.	3 to 4.1
Hymenaea courbaril L.	3.4 to 4.3
Hymenophyllum meyenianum Copel. [#]	4.7 to 5
Hymenostegia afzelii (Oliv.) Harms	4.9 to 5.1
Ilex amboroica Loes.	3.8 to 5.8
Ilex cochinchinensis (Lour.) Loes.	4.1 to 4.7
Ilex formosana Maxim.	3 to 5.6
Ilex goshiensis Hayata	3 to 4.1
Ilex hippocrateoides Kunth	3.7 to 4.3
Ilex lonicerifolia Hayata	4.1 to 4.7
Ilex mitis (L.) Radlk.	4.9 to 5.3
Ilex rimbachii Standl.	3.7 to 4.3
Ilex rotunda Thunb.	3 to 4.1
Ilex scopulorum Kunth	3.7 to 4.3
Ilex teratopis Loes.	3.7 to 4.3
Ilex triflora Blume	4.1 to 4.7
Ilex uraiensis Mori & Yamamoto	4.1 to 4.7
Ilex weberlingii Loizeau & Spichiger	3.7 to 4.3
Illicium anisatum Gaertn. [#]	3 to 4.1
Illicium arborescens Hayata	3 to 5.6
Inga extra-nodis T.D.Penn.	3.8 to 5.8
Inga heterophylla Willd.	3.4 to 4.3
Inga laurina (Sw.) Willd.	3.4 to 4.3
Inga marginata Kunth	3.8 to 5.8
Inga striata Benth.	3.8 to 5.8
Inga thibaudiana DC.	3.4 to 4.3
Isertia laevis (Triana) Boom	3.8 to 5.8
Itea parviflora Hemsl.	3.1 to 5.6

Species	pH range
Ixonanthes reticulata Jack[#]	3.8 to 4.2
Jacaranda copaia (Aubl.) D.Don	3.4 to 4.3
Jasminum humile L.	6.6 to 8.2
Korthalsia celebica Becc.	4.9 to 7.3
Kyllinga brevifolia Rottb.	5.4 to 6.7
Lacistema pubescens Mart. [#]	3.4 to 4.3
Ladenbergia acutifolia (Ruiz & Pav.) Klotzsch	3.8 to 5.8
Lagerstroemia subcostata Koehne	3.7 to 5.6
Laurocerasus phaeosticta (Hance) C.K. Schneid.	3 to 4.7
Lebruniodendron sp.	4.9 to 5.3
Leeuwenbergia africana Letouzey & N.Hallé	5.1 to 5.4
Leucaena leucocephala (Lam.) de Wit	5.4 to 6.7
Licania blackii Prance	3.4 to 4.3
Licania kunthiana Hook.f.	3.4 to 4.3
Licaria subsessilis van der Werff[#]	3.7 to 4.4
Ligularia fischeri (Ledeb.) Turcz.	6.6 to 8.2
Ligustrum japonicum Thunb.	3 to 4.1
Lindera communis Hemsl.	3.6 to 5.6
Lindsaea parallelogramma Alderw. [#]	4 to 4.1
Lithocarpus amygdalifolius (Skan) Hayata	4.1 to 4.7
Lithocarpus hancei (Benth.) Rehder	3.7 to 5.6
Litsea acuminata (Teschner) Kosterm.	3 to 3.7
Litsea acutivena Hayata	4.1 to 4.7
Lycopodiella cernua (L.) Pic. Serm.	3.8 to 4.2
Lyonia ovalifolia (Wall.) Drude	6.6 to 8.2
Mabea fistulifera Mart.	3.4 to 4.3
Machilus japonica var. kusanoi	3.7 to 5.6
Machilus thunbergii Siebold & Zucc.	3 to 5.6
Macrocarpaea revoluta (Ruiz & Pav.) Gilg	3.7 to 4.4
Magnolia compressa Maxim.	3 to 4.1
Magnolia kachirachirai (Kaneh. & Yamam.) Dandy	4.1 to 4.7
Mallotus paniculatus (Lam.) Müll.Arg.	4.1 to 4.7
Mapania graminea Uittien	3.7 to 4.6
Mapania monostachya Uittien	3.7 to 4.1
Maprounea guianensis Aubl.	3.4 to 4.3
Mareyopsis longifolia (Pax) Pax & K.Hoffm.	4.9 to 5.4

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Species	pH range
Matayba arborescens (Aubl.) Radlk.	3.4 to 4.3
Matayba inelegans Radlk.	3.5 to 4.4
Mauria heterophylla Kunth	3.8 to 5.8
Maytenus macrocarpa (Ruiz & Pav.) Briq.	3.8 to 5.8
Mazus japonicus (Thunb.) Kuntze	6.4 to 6.7
Melastoma malabathricum L.	3.8 to 4.7
Meliosma rhoifolia Maxim.	3 to 5.6
Meliosma squamulata Hance	3 to 4.1
Memecylon sp.	4.9 to 5.3
Meriania franciscana C. Ulloa & Homeier[#]	3.8 to 5.8
Meriania hexamera Sprague	3.8 to 5.8
Meriania rigida (Benth.) Triana	3.5 to 4.3
Mesophlebion falcatilobum Holttum[#]	3.7 to 4.1
Miconia calophylla (D. Don) Triana	3.5 to 4.3
Miconia capitellata Cogn.	3.5 to 4.3
Miconia crebribullata Wurdack	3.8 to 5.8
Miconia cuspidata Mart. ex Naudin	3.4 to 4.3
Miconia dispar Benth.	3.4 to 4.3
Miconia elaeagnoides Cogn.	3.4 to 4.3
Miconia holosericea (L.) DC.	3.4 to 4.3
Miconia jahnii Pittier	3.5 to 4.3
Miconia punctata (Desr.) D. Don ex DC.	3.8 to 5.8
Miconia pyrifolia Naudin	3.4 to 4.3
Miconia quadripora Wurdack	3.8 to 5.8
Miconia tetrasperma Gleason	3.4 to 4.3
Miconia theizans (Bonpl.) Cogn.	3.8 to 5.8
Miconia tinifolia Naudin	3.5 to 4.3
Microgramma percussa (Cav.) de la Sota	5.9 to 6.4
Microgramma piloselloides (L.) Copel.	5.9 to 6.4
Micropholis guyanensis (A.DC.) Pierre	3.5 to 5.8
Micropholis venulosa (Mart. & Eichler ex Miq.) Pierre	3.4 to 4.3
Microtropis japonica (Franch. & Sav.) Hallier f.	4.1 to 4.7
Minquartia guianensis Aubl.	3.4 to 4.3
Molineria latifolia (Dryand. ex W.T.Aiton) Herb. ex Kurz	3.7 to 4.1
Monodora tenuifolia Benth.	4.9 to 5.3
Monstera adansonii Schott	5.9 to 6.4
Morinda umbellata L.	3.8 to 4.2
Morus insignis Bureau	3.8 to 5.8
Mosla dianthera (Buch.-Ham. ex Roxb.) Maxim.	6.4 to 6.7
Musanga cecropioides R.Br. ex Tedlie	5.1 to 5.4
Myrcia sp.	3.5 to 4.3
Myrcia splendens (Sw.) DC.	3.4 to 4.3
Myrcianthes sp.	3.8 to 5.8
Myrciaria dubia (Kunth) McVaugh	3.4 to 4.3
Myrica rubra (Lour.) Siebold & Zucc.	3 to 5.6
Myrsine coriacea (Sw.) R.Br. ex Roem. & Schult.	3.5 to 4.3
Myrsine seguinii H. Lév.	3 to 4.1
Myrsine semiserrata Wall.	6.6 to 8.2
Nectandra cissiflora Nees	3.4 to 4.3
Nectandra cuspidata Nees & Mart.	3.4 to 5.8
Nectandra lineatifolia (Ruiz & Pav.) Mez	3.8 to 5.8
Nectandra subbullata Rohwer	3.8 to 5.8
Neea sp.	3.8 to 5.8
Neolitsea aciculata (Blume) Koidz.	3 to 4.1
Neolitsea hiiranensis Tang S. Liu & J.C. Liao	4.1 to 4.7
Nepenthes gracilis Korth. [#]	3.8 to 4.2
Nepenthes rafflesiana Jack[#]	3.8 to 4.2
Nephrolepis hirsutula (G. Forst.) C. Presl	4.9 to 5.5
Ocotea aciphylla (Nees & Mart.) Mez	3.7 to 4.4
Ocotea benthamiana Mez	3.7 to 4.4
Ocotea guianensis Aubl.	3.4 to 4.3
Ocotea oblongo-obovata (Nees) Rohwer	3.8 to 5.8
Oldenlandia cristata (Willd. ex Roem. & Schult.) ined.	3.8 to 4.2
Omphalocarpum sp.	5.1 to 5.8
Oplismenus undulatifolius (Ard.) Roem. & Schult.	5.4 to 6.7
Oreocnide pedunculata (Shirai) Masam.	3.7 to 5.6
Oreopanax confusus Marchal	3.8 to 5.8
Oreopanax microflorus Borchs.	3.8 to 5.8
Orites excelsa R.Br. [#]	4.5 to 7
Ormosia arborea (Vell.) Harms	3.4 to 4.3
Osmanthus marginatus (Champ. ex Benth.) Hemsl.	4.1 to 4.7
Osmanthus matsumuranus Hayata	3 to 3.7

Species	pH range
Ouratea discophora Ducke	3.4 to 4.3
Oxalis corniculata L.	5.4 to 6.7
Oxalis debilis var. corymbosa	5.4 to 6.7
Palicourea angustifolia Kunth	3.5 to 4.4
Palicourea canarina C.M.Taylor	3.8 to 5.8
Palicourea guianensis Aubl.	3.5 to 3.8
Palicourea loxensis C.M.Taylor	3.5 to 4.4
Palicourea luteonivea C.M.Taylor	3.8 to 5.8
Palicourea stenosepala Standl.	3.8 to 5.8
Panda oleosa Pierre	5.3 to 5.4
Paspalum distichum L.	5.4 to 6.7
Paspalum scrobiculatum L.	3.8 to 4.2
Paspalum thunbergii Kunth ex Steud.	6.4 to 6.7
Pera coccinea (Benth.) Müll.Arg.	3.4 to 4.3
Persea areolatocostae (C.K.Allen) van der Werff	3.7 to 4.4
Persea ruizii J.F.Macbr.	3.7 to 4.4
Persea subcordata (Ruiz & Pav.) Nees	3.7 to 4.4
Persea weberbaueri Mez	3.7 to 4.4
Philodendron acuminatissimum Engl.	5.9 to 6.4
Philodendron hederaceum (Jacq.) Schott	5.9 to 6.4
Philodendron subhastatum K.Krause	5.9 to 6.4
Phyllanthus urinaria L.	6.4 to 6.7
Physalis angulata var. angulata	6.4 to 6.7
Pilea umbrosa Blume	6.6 to 8.2
Piper arboreum Aubl.	3.8 to 5.8
Piper obliquum Ruiz & Pav.	3.8 to 5.8
Piper obtusilimbum C. DC.	3.8 to 5.8
Piper perareolatum C. DC.	3.8 to 5.8
Piptocoma discolor (Kunth) Pruski	3.7 to 5.8
Pittosporum sp.	5.3 to 5.4
Plagiostachys albiflora Ridl.	3.7 to 4.1
Plagiostachys strobilifera (Baker) Ridl.	3.7 to 4.6
Plantago major L.	6.4 to 6.7
Pleopeltis bombycina (Maxon) A.R. Sm.	5.9 to 6.4
Ploiarium alternifolium (Vahl) Melch.	3.8 to 4.2
Podocarpus oleifolius D.Don	3.5 to 4.3
Podocarpus rumphii Blume	4.1 to 4.7
Polyosma cunninghamii Benn. [#]	4.5 to 7
Pouteria austin-smithii (Standl.) Cronquist	3.5 to 5.8
Pouteria gardneri (Mart. & Eichler ex Miq.) Baehni	3.4 to 4.3
Protium guianense (Aubl.) Marchand	3.4 to 4.3
Protium unifoliolatum Engl.	3.4 to 4.3
Prumnopitys montana (Humb. & Bonpl. ex Willd.) de Laub.	3.8 to 5.8
Prunus africana (Hook. f.) Kalkman	4.9 to 5.4
Prunus opaca (Benth.) Walp.	3.5 to 4.3
Pseudolmedia macrophylla Trécul	3.4 to 4.3
Pseudolmedia rigida (Klotzsch & H.Karst.) Cuatrec.	3.8 to 5.8
Psychotria asiatica L.	4.1 to 4.7
Psychotria montivaga C.M.Taylor	3.8 to 5.8
Ptyssiglottis psychotriifolia (Stapf) B.Hansen[#]	3.7 to 4.1
Purdiaea nutans Planch.	3.7 to 4.4
Pycnanthus angolensis (Welw.) Warb.	5.1 to 5.8
Pyrenaria microcarpa var. microcarpa	3 to 4.1
Quercus championii Benth.	4.1 to 4.7
Quercus glauca Thunb.	3 to 5.6
Quercus lanata Sm.	6.6 to 8.2
Quercus longinux Hayata	3 to 5.6
Quercus pachyloma Seemen	4.1 to 4.7
Quercus semecarpifolia Sm.	6.6 to 8.2
Quercus sessilifolia Blume	3 to 4.1
Quiina yatuensis J.V.Schneid. & Zizka	3.8 to 5.8
Rapanea capitellata (Wall.) Mez	6.6 to 8.2
Rhaphiolepis indica var. hiiranensis	4.2 to 4.7
Rhaptopetalum sp.	4.9 to 5.4
Rhodamnia cinerea Jack	3.8 to 4.2
Rhododendron arboreum Sm.	6.6 to 8.2
Rhododendron latoucheae Franch.	3 to 4.1
Rhodomyrtus tomentosa (Aiton) Hassk.	3.8 to 4.2
Richeria grandis Vahl	3.8 to 5.8
Rinorea oblongifolia (C.H.Wright) C.Marquand ex Chipp	5.1 to 5.3
Rorippa indica (L.) Hiern	6.4 to 6.7
Rothmannia sp.	5.1 to 5.8
Ruagea glabra Triana & Planch.	3.8 to 5.8

Appendix S2.4

Species	pH range
Rubus biflorus Buch.-Ham. ex Sm.	6.6 to 8.2
Rudgea hospes Standl. & Steyerm.	3.5 to 5.8
Sacoglottis mattogrossensis Malme	3.4 to 4.3
Sapium glandulosum (L.) Morong	3.8 to 5.8
Saurauia tristyla DC.	3.7 to 5.6
Schefflera angulata (Pav.) Harms	3.7 to 4.3
Schefflera heptaphylla (L.) Frodin	3.6 to 5.6
Schima superba Gardner & Champ.	4.1 to 4.7
Schima wallichii Choisy	3.8 to 4.2
Schismatoglottis calyptrata (Roxb.) Zoll. & Moritzi	3.7 to 4.1
Schismatoglottis monoplacenta M.Hotta	3.7 to 4.1
Schlegelia darienensis Sandwith	5.9 to 6.4
Scindapsus pictus Hassk.	4 to 4.1
Scleria biflora Roxb.	3.8 to 4.2
Sclerolobium paniculatum Vogel	3.5 to 3.8
Scoparia dulcis L.	6.4 to 6.7
Selaginella delicatula (Desv. ex Poir.) Alston	4.5 to 5.5
Selinum wallichianum (DC.) Raizada & H.O. Saxena	6.6 to 8.2
Sericanthe sp.	5.3 to 5.4
Setaria viridis (L.) P.Beauv.	5.4 to 6.7
Shorea gibbosa Brandis[#]	4.2 to 4.5
Shorea hopeifolia (F.Heim) Symington[#]	4.2 to 4.5
Shorea laevis Ridl. [#]	4.2 to 4.5
Shorea lamellata Foxw. [#]	4.2 to 4.5
Shorea pauciflora King[#]	4.2 to 4.5
Sida rhombifolia L.	5.4 to 6.7
Simarouba amara Aubl.	3.4 to 4.3
Simira tinctoria Aubl.	3.5 to 5.8
Siparuna aspera (Ruiz & Pav.) A.DC.	3.5 to 5.8
Siparuna guianensis Aubl.	3.4 to 4.3
Siparuna thecaphora (Poepp. & Endl.) A.DC.	3.5 to 5.8
Siphoneugena sp.	3.5 to 4.3
Sloanea dasycarpa (Benth.) Hemsl.	4.1 to 4.7
Sloanea robusta Uittien	3.4 to 4.3
Smilax menispermoidea A.DC.	6.6 to 8.2
Solanum nutans Ruiz & Pav.	3.5 to 5.8
Sonchus arvensis L.	6.4 to 6.7
Sorindeia sp.	5.1 to 5.4
Sphaerostephanos hirsutus Holttum[#]	4.8 to 7.2
Stachyphrynium borneense Ridl.	4 to 4.1
Staurogyne jaheri Bremek. [#]	3.7 to 4.1
Stilpnophyllum oellgaardii L.Andersson	3.5 to 4.4
Strobilanthes urticifolia Wall. ex Kuntze	6.6 to 8.2
Strobilanthes wallichii Nees	6.6 to 8.2
Strombosia grandifolia Hook.f. ex Benth.	5.1 to 5.4
Strombosia pustulata Oliv.	5.1 to 5.7
Strombosia scheffleri Engl.	5.1 to 5.3
Strombosiopsis tetrandra Engl.	5.1 to 5.4
Styphelia malayana J.J.Sm. [#]	3.8 to 4.2
Styrax suberifolius Hook. & Arn.	3.6 to 5.6
Styrax trichostemon P.W.Fritsch[#]	3.5 to 4.4
Symphonia globulifera L.f.	5.1 to 5.7
Symplocos bogotensis Brand	3.5 to 4.4
Symplocos cochinchinensis var. laurina	3.1 to 5.6
Symplocos fuscata B. Ståhl	3.5 to 4.4
Symplocos lucida (Thunb.) Siebold & Zucc.	3 to 4.1
Symplocos sumuntia Buch.-Ham. ex D. Don	3 to 4.1
Symplocos wikstroemiifolia Hayata	3 to 4.1
Syngonium crassifolium (Engl.) Croat	5.9 to 6.4
Synotis wallichii (DC.) C.Jeffrey & Y.L.Chen	6.6 to 8.2
Synsepalum sp.	5.1 to 5.7
Syzygium buxifolium Hook. & Arn.	3 to 4.7
Syzygium euphlebium (Hayata) Mori	4.1 to 4.7
Tabernaemontana crassa Benth.	5.1 to 5.4
Taenitis blechnoides (Willd.) Sw.	3.8 to 4.2
Tapirira guianensis Aubl.	3.4 to 5.8
Tectaria barberi (Hook.) Copel.	3.7 to 4.1
Ternstroemia cleistogama Kobuski	3.5 to 4.4
Ternstroemia gymnanthera (Wight & Arn.) Bedd.	3 to 4.1
Ternstroemia jelskii (Szyszyl.) Melch.	3.5 to 4.4
Thalictrum foliolosum DC.	6.6 to 8.2
Thyrsodium spruceanum Benth.	3.4 to 4.3
Timonius flavescens (Jacq.) Baker	3.8 to 4.2

Species	pH range
Torenia concolor Lindl.	6.4 to 6.7
Torilis scabra (Thunb.) DC.	5.4 to 6.7
Tovomita weddeliana Planch. & Triana	3.7 to 4.3
Triadica cochinchinensis Lour.	4.1 to 4.7
Tricalysia sp.	5.4 to 5.5
Trichilia micrantha Benth.	3.4 to 4.3
Trichomanes singaporianum Alderw. #	3.7 to 4.6
Tridesmostemon omphalocarpoides Engl.	5.1 to 5.8
Trilepisium madagascariense DC.	5.3 to 5.4
Tristaniopsis obovata (Benn.) Peter G.Wilson & J.T.Waterh.	3.8 to 4.2
Trochodendron aralioides Siebold & Zucc.	3 to 4.1
Turpinia formosana Nakai	3.7 to 5.6
Turpinia occidentalis (Sw.) G.Don	3.5 to 5.8
Uvariodendron connivens (Benth.) R.E. Fr.	4.9 to 5.7
Uvariodendron sp.	4.9 to 5.3
Uvariopsis congolana (De Wild.) R.E. Fr.	4.9 to 5.3
Vatica sp.	4.2 to 4.5
Viburnum oliganthum Batalin	3.8 to 5.8
Viola arcuata Blume	6.4 to 6.7
Virola sebifera Aubl.	3.4 to 4.3
Viscum articulatum Burm. f.	3.8 to 4.2
Vismia japurensis Rchb.f.	3.4 to 4.3
Vismia tomentosa Ruiz & Pav.	3.8 to 5.8
Vochysia ferruginea Mart.	3.4 to 4.3
Weinmannia elliptica Kunth	3.7 to 4.4
Weinmannia fagaroides Kunth	3.7 to 4.4
Weinmannia haenkeana Engl.	3.7 to 4.4
Weinmannia magnifolia Cuatrec.	3.7 to 4.4
Weinmannia ovata Cav.	3.7 to 4.4
Weinmannia pinnata L.	3.7 to 4.4
Weinmannia spruceana Engl.	3.8 to 5.8
Wendlandia formosana Cowan	3.6 to 5.6
Xanthium sibiricum Patrin ex Widder	6.4 to 6.7
Xylopia amazonica R.E.Fr.	3.4 to 4.3
Xylopia benthamii R.E.Fr.	3.4 to 4.3
Xylopia frutescens Aubl.	3.4 to 4.3

Species	pH range
Youngia japonica (L.) DC.	6.4 to 6.7
Zanthoxylum sp.	5.1 to 5.4
(b) Tropical and subtropical grassland, savanna, and shrubland	
Acosmium dasycarpum (Vogel) Yakovlev	4.5 to 4.9
Acosmium subelegans (Mohlenbr.) Yakovlev	4.9 to 5.3
Aegiphila lhotzkiana Cham.	4.7 to 4.8
Allagoptera campestris (Mart.) Kuntze	4.9 to 5.3
Allagoptera leucocalyx (Drude) Kuntze	4.7 to 4.9
Anacardium humile A.St.-Hil.	4.7 to 4.9
Anadenanthera peregrina (L.) Speg.	4.5 to 6.1
Andira laurifolia Benth.	5 to 5.3
Andropogon leucostachyus Kunth	5 to 5.3
Annona crassiflora Mart.	4.5 to 5.1
Annona warmingiana Mello-Silva & Pirani	4.9 to 5.1
Anthaenantiopsis perforata (Nees) Parodi	4.9 to 5.1
Aspidosperma parvifolium A.DC.	4.5 to 6.1
Aspilia leucoglossa Malme	4.9 to 5.1
Axonopus comans (Döll) Kuhlm.	4.7 to 5.3
Axonopus pressus (Steud.) Parodi	4.9 to 5.3
Bauhinia rufa (Bong.) Steud.	4.5 to 4.7
Brachiaria decumbens Stapf	5 to 5.3
Byrsonima coccolobifolia Kunth	4.5 to 4.8
Byrsonima guilleminiana A.Juss.	4.9 to 5.1
Byttneria oblongata Pohl	4.9 to 5.3
Campomanesia pubescens (Mart. ex DC.) O.Berg	4.5 to 5.1
Camptosema ellipticum (Desv.) Burkart	4.9 to 5.1
Caryocar brasiliense A.St.-Hil.	4.5 to 4.8
Casearia sylvestris Sw.	4.5 to 4.8
Chresta sphaerocephala DC.	4.7 to 4.9
Chromolaena squalida (DC.) R.M.King & H.Rob.	4.7 to 4.9
Coccocypselum lymansmithii Standl.	4.7 to 5.3
Copaifera langsdorffii Desf.	4.5 to 6.1
Croton antisyphiliticus Mart.	4.9 to 5.1
Croton glandulosus L.	4.7 to 5.3
Cuphea carthagenensis (Jacq.) J.F.Macbr.	4.9 to 5.1

Appendix S2.4

Species	pH range
Davilla elliptica A.St.-Hil.	4.5 to 5.1
Dimorphandra mollis Benth.	4.5 to 4.9
Diospyros hispida A.DC.	4.5 to 5.1
Drosera communis A.St.-Hil.	4.7 to 5.3
Duguetia furfuracea (A.St.-Hil.) Saff.	4.7 to 4.9
Elionurus muticus (Spreng.) Kuntze	4.7 to 5.3
Eragrostis articulata (Schrank) Nees	4.9 to 5.1
Eragrostis bahiensis Roem. & Schult.	4.7 to 5.3
Erechtites hieracifolia (L.) Raf.	5 to 5.3
Eremanthus erythropappus (DC.) MacLeish	4.5 to 4.9
Eriosema crinitum (Kunth) G.Don	4.9 to 5.1
Eriosema longifolium Benth.	4.9 to 5.1
Eriotheca gracilipes (K.Schum.) A.Robyns	4.5 to 4.8
Eriotheca pubescens (Mart. & Zucc.) Schott & Endl.	4.5 to 4.8
Erythroxylum campestre A.St.-Hil.	4.5 to 4.9
Erythroxylum deciduum A.St.-Hil.	4.9 to 5.1
Erythroxylum suberosum A.St.-Hil.	4.5 to 5.1
Eugenia angustissima O.Berg	4.9 to 5.1
Eugenia calycina Cambess.	4.9 to 5.1
Eugenia complicata O.Berg	5 to 5.3
Eugenia livida O.Berg	4.5 to 5.3
Eugenia punicifolia (Kunth) DC.	4.5 to 4.8
Eugenia stictopetala DC.	4.7 to 4.9
Festuca subverticillata (Pers.) E.B.Alexeev	4.7 to 5.3
Froelichia procera (Seub.) Pedersen	4.9 to 5.1
Galactia decumbens Hoehne	4.9 to 5.1
Galactia martii DC.	4.9 to 5.3
Gaylussacia brasiliensis (Spreng.) Meisn.	4.7 to 5.3
Himatanthus obovatus (Müll.Arg.) Woodson	4.7 to 4.8
Hovenia dulcis Thunb.	4.5 to 6.1
Hymenaea courbaril L.	4.5 to 6.1
Hypoxis sp.	4.7 to 5.3
Hyptis adpressa A.St.-Hil. ex Benth.	4.9 to 5.1
Hyptis pulchella Briq.	4.7 to 5.3
Hyptis villosa Pohl ex Benth.	4.9 to 5.1
Jacaranda mimosifolia D.Don	4.5 to 6.1
Kielmeyera coriacea Mart. & Zucc.	4.5 to 4.8
Lafoensia pacari A.St.-Hil.[#]	4.5 to 4.7
Lessingianthus bardanoides (Less.) H.Rob.	4.7 to 4.9
Luehea grandiflora Mart.	4.5 to 6.1
Lycopodiella cernua (L.) Pic. Serm.	4.7 to 5.3
Machaerium acutifolium Vogel	4.5 to 4.9
Manihot tripartita (Spreng.) Müll.Arg.	4.7 to 4.9
Melinis repens (Willd.) Zizka	4.9 to 5.1
Miconia albicans (Sw.) Steud.	4.5 to 4.7
Miconia ferruginata DC. [#]	4.5 to 4.8
Mimosa amnis-atri Barneby[#]	4.5 to 4.9
Mimosa gracilis Benth.	4.9 to 5.1
Myrcia tomentosa (Aubl.) DC.	4.9 to 5.3
Myrcia uberavensis O.Berg	4.9 to 5.3
Ocimum sp.	4.9 to 5.3
Ouratea acuminata (DC.) Engl.	4.5 to 4.9
Ouratea nana (A. St.-Hil.) Engl.	4.9 to 5.1
Ouratea spectabilis (Mart. ex Engl.) Engl.	4.5 to 5.1
Palicourea rigida Kunth	4.5 to 4.9
Panicum parvifolium Lam.	5 to 5.3
Panicum rudgei Roem. & Schult.	4.9 to 5.3
Paspalum dedeccae Quarín	4.7 to 5.3
Paspalum maculosum Trin.	4.7 to 5.3
Paspalum pectinatum Nees	4.9 to 5.1
Peltaea edouardii (Hochr.) Krapov. & Cristobal	4.9 to 5.1
Peltophorum dubium (Spreng.) Taub.	4.5 to 6.1
Phyllanthus niruri L.	4.7 to 5.3
Piptocarpha rotundifolia (Less.) Baker	4.5 to 4.9
Platycyamus regnellii Benth.	4.5 to 6.1
Pouteria ramiflora (Mart.) Radlk.	4.5 to 4.9
Pouteria torta (Mart.) Radlk.	4.5 to 4.9
Pradosia brevipes (Pierre) T.D.Penn.	4.9 to 5.1
Psidium australe Cambess.	4.9 to 5.3
Psidium grandifolium Mart. ex DC.	4.9 to 5.1
Psidium laruotteanum Cambess.	4.5 to 5.1
Psidium rufum Mart. ex DC.	4.9 to 5.1
Qualea grandiflora Mart.	4.5 to 4.8

Species	pH range
Qualea parviflora Mart.	4.7 to 4.8
Rhynchospora globosa (Kunth) Roem. & Schult.	4.7 to 5.3
Rhynchospora leucostachys Boeckeler	4.7 to 5.3
Roupala montana Aubl.	4.5 to 4.7
Rourea induta var. induta#	4.5 to 5.1
Salacia micrantha (Mart. ex Schult.) G. Don	4.9 to 5.3
Schinus terebinthifolia Raddi	4.5 to 6.1
Schizachyrium tenerum Nees	4.7 to 5.3
Sclerolobium sp.	4.5 to 4.7
Senna macranthera (Collad.) H.S.Irwin & Barneby	4.5 to 6.1
Senna multijuga (Rich.) H.S.Irwin & Barneby	4.5 to 6.1
Serjania cissoides Radlk. #	4.9 to 5.1
Sisyrinchium vaginatum Spreng.	4.7 to 5.3
Solanum lycocarpum A. St.-Hil.	4.5 to 4.9
Stachytarpheta linearis Moldenke	4.7 to 5.3
Stryphnodendron adstringens (Mart.) Coville	4.5 to 4.9
Syagrus flexuosa (Mart.) Becc.	4.9 to 5.1
Tabebuia aurea (Silva Manso) Benth. & Hook.f. ex S.Moore	4.5 to 4.8
Tabebuia ochracea A.H. Gentry	4.5 to 5.1
Tetrapollinia caerulescens (Aubl.) Maguire & B.M.Boom	4.7 to 5.3
Trachypogon sp.	4.7 to 5.3
Trema micrantha (L.) Blume	4.5 to 6.1
Tristachya leiostachya Nees	4.9 to 5.1
Waltheria communis A.St.-Hil.	4.9 to 5.1
Wedelia macedoi H.Rob. #	4.9 to 5.1
Xyris sp.	4.7 to 5.3
(c) Mangrove	
Acanthus ilicifolius L.	3.4 to 7.1
Acrostichum speciosum (Fée) C. Presl	4.1 to 7.1
Avicennia germinans (L.) L.	3.9 to 6.9
Avicennia marina (Forssk.) Vierh.	4.1 to 6.9
Bassia prostrata (L.) Beck	3.6 to 6
Bruguiera gymnorhiza (L.) Lam.	4.3 to 7.2
Bruguiera parviflora (Roxb.) Wight & Arn. ex Griff.	4.1 to 7.1
Ceriops tagal (Perr.) C.B.Rob.	3.4 to 7.2
Conocarpus erectus L.	4.1 to 7.1
Derris trifoliata Lour.	4.1 to 6.5
Halimodendron halodendron (Pall.) Voss	4.1 to 7.1
Heritiera littoralis Aiton	3.6 to 7.1
Nypa fruticans Wurmb	3.4 to 7.1
Pandanus candelabrum P.Beauv.	3.4 to 7.1
Pandanus odorifer (Forssk.) Kuntze	4.1 to 7.1
Phoenix reclinata Jacq.	3.9 to 7.1
Raphia hookeri G.Mann & H.Wendl.	3.6 to 7.1
Rhizophora apiculata Blume	3.4 to 7.2
Rhizophora harrisonii Leechm.	3.4 to 7.1
Rhizophora mangle L.	3.6 to 6.9
Rhizophora mucronata Lam.	4.1 to 7.1
Rhizophora racemosa G.Mey.	3.9 to 6.9
Salsola pellucida Litv.	3.4 to 7
Sonneratia alba Sm.	4.3 to 7.1
Taraxacum mongolicum Hand.-Mazz.	3.6 to 6
(d) Tropical and subtropical dry broadleaf forest	
Acacia gaumeri S.F.Blake	6.9 to 7.3
Acacia polyphylla DC.	5.5 to 6.5
Adelia oaxacana (Müll.Arg.) Hemsl.	7 to 7.3
Aegiphila sellowiana Cham.	5.5 to 6.5
Albizia niopoides (Benth.) Burkart	5.5 to 6.5
Aloysia virgata (Ruiz & Pav.) Juss.	5.5 to 6.5
Anadenanthera colubrina (Vell.) Brenan	5.5 to 6.5
Apeiba tibourbou Aubl.	5.5 to 6.5
Ardisia escallonioides Schltdl. & Cham.	6.9 to 7.1
Aspidosperma olivaceum Müll.Arg.	5.5 to 6.5
Aspidosperma subincanum Mart. ex A.DC.	5.5 to 6.5
Astrocasia tremula (Griseb.) G.L.Webster	6.9 to 7.5
Astronium fraxinifolium Schott	5.5 to 6.5
Attalea phalerata Mart. ex Spreng.	5.5 to 6.5
Bauhinia divaricata L.	6.9 to 7.3
Bauhinia ungulata L.	5.5 to 6.5
Bourreria pulchra (Millsp.) Millsp. ex Green.	6.9 to 7.6
Brosimum alicastrum Sw.	6.9 to 8.5

Appendix S2.4

Species	pH range
Bunchosia swartziana Griseb.	6.9 to 7.6
Bursera schlechtendalii Engl.	7 to 7.3
Bursera simaruba (L.) Sarg.	6.9 to 7.6
Caesalpinia gaumeri Greenm.	6.9 to 7.3
Caesalpinia velutina (Britton & Rose) Standl.	6.9 to 7.2
Campomanesia velutina (Cambess.) O.Berg	5.5 to 6.5
Casearia corymbosa Kunth	7 to 7.3
Casearia gossypiosperma Briq.	5.5 to 6.5
Casearia mariquitensis Kunth	5.5 to 6.5
Casearia sylvestris Sw.	5.5 to 6.5
Cecropia pachystachya Trécul	5.5 to 6.5
Cedrela fissilis Vell.	5.5 to 6.5
Cedrela odorata L.	7.3 to 8.5
Celtis iguanaea (Jacq.) Sarg.	5.5 to 7.5
Chloroleucon mangense var. leucospermum	6.9 to 7.6
Chomelia ribesioides Benth. ex A.Gray	5.5 to 6.5
Coccoloba cozumelensis Hemsl.	6.9 to 7.1
Coccoloba spicata Lundell	6.9 to 7.1
Cochlospermum vitifolium (Willd.) Spreng.	5.7 to 7
Colubrina elliptica (Sw.) Brizicky & W.L.Stern	7.2 to 7.3
Colubrina greggii S.Watson	7 to 7.3
Cordia alliodora (Ruiz & Pav.) Oken	5.5 to 6.5
Cordia gerascanthus L.	6.9 to 7.6
Cosmocalyx spectabilis Standl.	6.9 to 7.6
Croton oerstedianus Müll.Arg.	7.5 to 7.6
Croton reflexifolius Kunth	6.9 to 7.5
Cupania vernalis Cambess.	5.5 to 6.5
Dialium guianense (Aubl.) Sandwith	7.3 to 8.5
Dilodendron bipinnatum Radlk.	5.5 to 6.5
Diospyros anisandra S.F.Blake	7 to 7.6
Diospyros tetrasperma Sw.	6.9 to 7.2
Diphysa carthagenensis Jacq.	6.9 to 7.3
Drypetes lateriflora (Sw.) Krug & Urb.	6.9 to 7.6
Ehretia tinifolia L.	7 to 7.5
Erythroxylum rotundifolium Lunan	6.9 to 7.2
Eugenia axillaris (Sw.) Willd.	6.9 to 7.6
Eugenia bimarginata DC.	5.5 to 6.5
Eugenia buxifolia Lam.	6.9 to 7.6
Eugenia florida DC.	5.5 to 6.5
Eugenia moraviana O.Berg	5.5 to 6.5
Eupatorium sp.	5.5 to 6.5
Exostema caribaeum (Jacq.) Schult.	6.9 to 7.6
Ficus sp.	6.9 to 7.2
Genipa americana L.	5.5 to 6.5
Guarea guidonia (L.) Sleumer	5.5 to 6.5
Guarea macrophylla Vahl	5.5 to 6.5
Guazuma ulmifolia Lam.	5.5 to 6.5
Guettarda combsii Urb.	6.9 to 7
Guettarda elliptica Sw.	7 to 7.3
Guettarda gaumeri Standl.	6.9 to 7.1
Gymnanthes lucida Sw.	6.9 to 7.6
Gymnopodium floribundum Rolfe	6.9 to 7.3
Hampea trilobata Standl.	6.9 to 7.1
Handroanthus impetiginosus (Mart. ex DC.) Mattos	5.5 to 6.5
Havardia albicans (Kunth) Britton & Rose	7 to 7.3
Hybanthus yucatanensis Millsp.	7.5 to 7.6
Hymenaea courbaril L.	5.5 to 6.5
Inga pinetorum Pittier	5.7 to 6.3
Inga vera Willd.	5.5 to 6.5
Jacaranda jasminoides (Thunb.) Sandwith	5.5 to 6.5
Jatropha gaumeri Greenm.	6.9 to 7.3
Krugiodendron ferreum (Vahl) Urb.	6.9 to 7.6
Lonchocarpus guillemineanus (Tul.) Malme	5.5 to 6.5
Lonchocarpus rugosus Benth.	6.9 to 7
Lonchocarpus yucatanensis Pittier	6.9 to 7.3
Luehea speciosa Willd.	6.9 to 7.1
Lysiloma latisiliquum (L.) Benth.	6.9 to 7.3
Machaerium aculeatum Raddi	5.5 to 6.5
Machaerium paraguariense Hassl.	5.5 to 6.5
Machaerium stipitatum (DC.) Vogel	5.5 to 6.5
Machaerium villosum Vogel	5.5 to 6.5
Machaonia lindeniana Baill.	7.1 to 7.2
Maclura tinctoria (L.) D.Don ex Steud.	5.5 to 6.5

Species	pH range
Malmea depressa (Baill.) R.E. Fr.	6.9 to 7.6
Malpighia glabra L.	7 to 7.1
Manilkara chicle (Pittier) Gilly	7.3 to 8.5
Manilkara zapota (L.) P.Royen	6.9 to 8.5
Maytenus pittieriana Steyerm.	5.5 to 6.5
Melicoccus oliviformis Kunth	6.9 to 7.6
Mimosa bahamensis Benth.	7 to 7.3
Myracrodruon urundeuva Allemão	5.5 to 6.5
Myrcia splendens (Sw.) DC.	5.5 to 6.5
Myrcia tomentosa (Aubl.) DC.	5.5 to 6.5
Myrsine umbellata Mart.	5.5 to 6.5
Nectandra coriacea (Sw.) Griseb.	6.9 to 7.6
Neea psychotrioides Donn. Sm.	7 to 7.5
Neomillspaughia emarginata (H. Gross) S.F. Blake	6.9 to 7.2
Parmentiera aculeata (Kunth) Seem.	7 to 7.2
Phyllanthus acuminatus Vahl	5.5 to 6.5
Pinus caribaea var. hondurensis	5.7 to 6.3
Pinus oocarpa Schiede	5.7 to 6.3
Piptadenia gonoacantha (Mart.) J.F.Macbr.	5.5 to 6.5
Piscidia piscipula (L.) Sarg.	6.9 to 7.6
Pithecellobium dulce (Roxb.) Benth.	7 to 7.3
Platypodium elegans Vogel	5.5 to 6.5
Pouteria torta (Mart.) Radlk.	5.5 to 6.5
Protium copal (Schltdl. & Cham.) Engl.	7.3 to 8.5
Psidium sartorianum (O.Berg) Nied.	5.5 to 7.1
Quercus oleoides Schltdl. & Cham.	5.7 to 6.3
Randia obcordata S.Watson	7 to 7.3
Rhamnidium elaeocarpum Reissek	5.5 to 6.5
Rhamnus humboldtiana Willd. ex Schult.	7.1 to 7.6
Rollinia sylvatica (A. St.-Hil.) Martius	5.5 to 6.5
Sabal mauritiiformis (H.Karst.) Griseb. & H.Wendl.	7.3 to 8.5
Schizolobium parahyba (Vell.) S.F.Blake	7.3 to 8.5
Sebastiania tuerckheimiana (Pax & K.Hoffm.) Lundell	7.3 to 8.5
Semialarium mexicanum (Miers) Mennega	6.9 to 7.6
Senna racemosa (Mill.) H.S.Irwin & Barneby	7 to 7.3
Sideroxylon foetidissimum subsp. gaumeri (Pittier) T.D.Penn.	6.9 to 7.3
Spondias mombin L.	6.9 to 8.5
Swietenia macrophylla King	7.3 to 8.5
Tabebuia ochracea A.H. Gentry	5.5 to 6.5
Tabebuia roseoalba (Ridl.) Sandwith	5.5 to 6.5
Terminalia phaeocarpa Eichler[#]	5.5 to 6.5
Thouinia paucidentata Radlk.	6.9 to 7.6
Trichilia catigua A.Juss.	5.5 to 6.5
Trichilia pallida Sw.	5.5 to 6.5
Urera baccifera (L.) Gaudich.	7.5 to 7.6
Vitex gaumeri Greenm.	6.9 to 8.5
Zanthoxylum riedelianum Engl.	5.5 to 6.5
Zuelania guidonia (Sw.) Britton & Millsp.	6.9 to 7.6
(e) Flooded grassland and savanna	
Bulbostylis cardiocarpoides Cherm.	5.3 to 6.9
Bulbostylis coleotricha (Hochst. ex A.Rich.) C.B.Clarke	5.3 to 6.9
Cyperus compressus L.	5.3 to 6.9
Cyperus cyperoides (L.) Kuntze	5.3 to 6.9
Cyperus denudatus L.f.	5.3 to 6.9
Cyperus difformis L.	5.3 to 6.9
Cyperus digitatus subsp. auricomus (Sieber ex Spreng.) Kük.	5.3 to 6.9
Cyperus iria L.	5.3 to 6.9
Cyperus papyrus L.	5.3 to 6.9
Cyperus pectinatus Vahl	5.3 to 6.9
Fuirena umbellata Rottb.	5.3 to 6.9
Mouriri guianensis Aubl.	5.9 to 6.6
Pseudobombax sp.	5.9 to 6.6
Salacia elliptica (Mart.) G.Don	5.9 to 6.6
Trichilia catigua A.Juss.	5.9 to 6.6
Triplaris americana L.	5.9 to 6.6
Vitex cymosa Bertero ex Spreng.	5.9 to 6.6
Vochysia divergens Pohl[#]	5.9 to 6.6
(f) Desert and xeric shrubland	
Abutilon angulatum (Guill. & Perr.) Mast.	7 to 8
Abutilon fruticosum Guill. & Perr.	6.6 to 7.5

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Species	pH range
Abutilon pannosum (G.Forst.) Schltdl.	7.3 to 9.3
Abutilon ramosum (Cav.) Guill. & Perr.	7 to 8
Acacia cochliacantha Willd.	5.1 to 6.9
Acacia constricta A.Gray	5.2 to 7.5
Acacia farnesiana (L.) Willd.	5.1 to 6.8
Acacia grandicornuta Gerstner	7 to 8
Acacia robusta Burch.	7 to 8
Acacia tortilis (Forssk.) Hayne	6.2 to 9.3
Acalypha indica L.	7 to 8
Acanthospermum hispidum DC.	7 to 8
Aeluropus lagopoides (L.) Thwaites	6.2 to 9.7
Aeluropus littoralis (Gouan) Parl.	6.3 to 9.7
Aerva javanica (Burm.f.) Juss. ex Schult.	6.2 to 9.4
Agave cerulata Trel.	6.6 to 7.7
Agave deserti Engelm.	6.2 to 7.7
Agave kerchovei Lem.	7.4 to 7.5
Agave marmorata Roezl	7.2 to 7.5
Agave salmiana Otto ex Salm-Dyck	7.2 to 7.4
Agave triangularis Jacobi	7.2 to 7.4
Agriophyllum montasirii El Gazzar	7.1 to 8.3
Agriophyllum squarrosum (L.) Moq.	7.4 to 7.6
Alhagi maurorum Medik.	7.2 to 8.5
Alhagi sparsifolia Shap.	6.4 to 9.7
Aloe vera (L.) Burm.f.	6.2 to 9.3
Amaranthus viridis L.	6.7 to 7
Ambrosia camphorata (Greene) W.W.Payne	6.2 to 7.7
Ambrosia chenopodiifolia (Benth.) W.W.Payne	6.9 to 7.7
Ambrosia deltoidea (Torr.) W.W.Payne	6.6 to 8.7
Ambrosia dumosa (A.Gray) W.W.Payne	7.6 to 8.6
Anabasis articulata (Forssk.) Moq.	6.6 to 9.4
Anabasis setifera Moq.	7.3 to 7.5
Anthemis melampodina Delile	7.1 to 7.9
Apocynum venetum L.	6.4 to 9.8
Argemone ochroleuca Sweet	7 to 8
Aristida adscensionis L.	7 to 8
Arnebia hispidissima (Lehm.) A.DC.	7.2 to 8.3
Artemisia monosperma Delile	6.6 to 9.2
Artemisia ordosica Krasch.	7.4 to 8.6
Arthrocnemum macrostachyum (Moric.) K.Koch	7.3 to 8.3
Asparagus natalensis (Baker) J.-P.Lebrun & Stork	7 to 8
Astragalus hamosus L.	6.6 to 9.4
Atriplex barclayana (Benth.) D.Dietr.	6.2 to 7.7
Atriplex canescens (Pursh) Nutt.	6.6 to 7
Atriplex crassifolia Ledeb.	7.7 to 7.9
Atriplex leucoclada Boiss.	7.3 to 7.7
Atriplex polycarpa (Torr.) S.Watson	6.9 to 7.3
Baccharis sp.	5.2 to 6.4
Barleria elegans S.Moore	7 to 8
Barleria prionitis L.	7 to 8
Bassia dasyphylla (Fisch. & C.A.Mey.) Kuntze	7.4 to 7.6
Bassia muricata (L.) Asch.	7.4 to 7.7
Bassia prostrata (L.) Beck	7.3 to 7.6
Beaucarnea gracilis Lem.	7.4 to 7.5
Bidens biternata (Lour.) Merr. & Sherff	7 to 8
Bidens pilosa L.	7 to 8
Blepharis ciliaris (L.) B.L.Burtt	6.2 to 9.3
Breonadia salicina (Vahl) Hepper & J.R.I.Wood	7 to 8
Bridelia cathartica Bertol.	7 to 8
Buddleja sp.	7.4 to 7.5
Bursera fagaroides (Kunth) Engl.	7.2 to 7.4
Cakile arabica Velen.	7.1 to 7.9
Calliandra eriophylla Benth.	7.2 to 7.5
Calligonum comosum L'Hér.	7.2 to 8.3
Calotropis procera (Aiton) Dryand.	5.6 to 9.4
Caragana korshinskii Kom.	7.4 to 7.6
Caralluma penicillata (Deflers) N.E.Br.	7.3 to 9.3
Cardiospermum halicacabum L.	7 to 8
Carnegiea gigantea (Engelm.) Britton & Rose	6.6 to 8.7
Carthamus oxyacanthus M.Bieb.	7.4 to 7.7
Cassia abbreviata Oliv.	7 to 8
Cassia italica (Mill.) Lam. ex F.W. Andrews	6.2 to 8.5
Cassytha filiformis L.	7 to 8
Catharanthus roseus (L.) G.Don	7 to 8

Species	pH range
Cenchrus ciliaris L.	7.7 to 7.9
Centaurea aegyptiaca L.	6.7 to 9.2
Centaurea pallescens Delile	6.7 to 9.4
Centella asiatica (L.) Urb.	7 to 8
Cercidium microphyllum (Torr.) Rose & I.M.Johnst.	6.6 to 8.7
Chenopodium album L.	7.4 to 7.6
Chloris barbata Sw.	6.7 to 7.5
Chloris gayana Kunth	7 to 8
Chloris roxburghiana Schult.	7 to 8
Cissampelos mucronata A.Rich.	7 to 8
Cissus quadrangularis L.	7.9 to 8.5
Cissus rotundifolia Vahl	7 to 8
Citrullus colocynthis (L.) Schrad.	6.4 to 9.4
Cleistogenes songorica (Roshev.) Ohwi	7.4 to 7.6
Cleome amblyocarpa Barratte & Murb.	6.6 to 9.4
Cleome monophylla L.	7 to 8
Cleome viscosa L.	7.5 to 7.8
Combretum apiculatum Sond.	7 to 8
Combretum erythrophyllum (Burch.) Sond.	7 to 8
Combretum hereroense Schinz	7 to 8
Combretum imberbe Wawra	7 to 8
Combretum microphyllum Klotzsch	7 to 8
Combretum mossambicense (Klotzsch) Engl.	7 to 8
Commelina diffusa Burm.f.	7 to 8
Corchorus depressus (L.) Stocks	6.2 to 9.3
Corchorus trilocularis L.	7.2 to 7.3
Cordia curassavica (Jacq.) Roem. & Schult.	5.2 to 6.4
Cordia monoica Roxb.	7 to 8
Coriandrum sativum L.	7.3 to 7.6
Cornulaca aucheri Moq.	7.1 to 7.9
Cornulaca monacantha Delile	6.6 to 9.4
Cressa cretica L. [#]	6.3 to 9.7
Crotalaria aegyptiaca Benth.	6.6 to 9.4
Croton ciliatoglanduliferus Ortega[#]	5.1 to 7.5
Cryptolepis obtusa K.Schum.	7 to 8
Cylindropuntia acanthocarpa (Engelm. & J.M.Bigelow) F.M.Knuth	6.6 to 8.7
Cylindropuntia cholla (F.A.C.Weber) F.M.Knuth	6.6 to 7
Cylindropuntia molesta (Brandegee) F.M.Knuth	6.2 to 7.7
Cynodon dactylon (L.) Pers.	7 to 9.5
Cyperus conglomeratus Rottb.	6.3 to 9.7
Cyperus difformis L.	8.1 to 8.5
Cyperus rotundus L.	7.7 to 9.5
Cyperus sexangularis Nees	7 to 8
Dalea sp.	7.2 to 7.4
Dasylirion sp.	7.2 to 7.4
Desmostachya bipinnata (L.) Stapf	7.7 to 9.8
Deverra tortuosa DC.	6.7 to 9.4
Dichrostachys cinerea (L.) Wight & Arn.	7 to 8
Diospyros mespiliformis Hochst. ex A.DC.	7 to 8
Dipterygium glaucum Decne.	6.2 to 9.3
Dodonaea viscosa Jacq.	5.2 to 6.4
Echinocactus platyacanthus Link & Otto	7.4 to 7.5
Echinocereus engelmannii (Parry ex Engelm.) Lem.	6.2 to 7.7
Echinochloa colona (L.) Link	8.1 to 9.5
Echinops polyceras Boiss.	7.1 to 8.3
Echinops spinosissimus Turra	6.6 to 9.4
Ehretia amoena Klotzsch	7 to 8
Encelia sp.	6.2 to 7.7
Ephedra aspera Engelm. ex S.Watson	6.2 to 7.7
Eragrostis heteromera Stapf	7 to 8
Eragrostis minor Host	7.4 to 7.6
Eragrostis superba Peyr.	7 to 8
Eremobium aegyptiacum (Spreng.) Asch. ex Boiss.	7.1 to 8.3
Ericameria brachylepis (A.Gray) H.M.Hall	6.2 to 7.6
Eriogonum fasciculatum Benth.	6.2 to 7.7
Eriogonum scalare S.Watson	6.6 to 7
Erodium glaucophyllum (L.) L'Hér.	6.8 to 9.4
Erodium oxyrhinchum subsp. bryoniifolium (Boiss.) Schönb.-Tem.	7.1 to 8.3
Escontria chiotilla (A.A.Weber ex K.Schum.) Rose	5.2 to 6.9
Euclea divinorum Hiern	7 to 8
Euclea natalensis A.DC.	7 to 8

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Species	pH range
Euphorbia heterophylla L.	7 to 8
Euphorbia hirta L.	7 to 8
Euphorbia inarticulata Schweinf.	6.2 to 9.3
Eysenhardtia polystachya (Ortega) Sarg.	5.1 to 6.8
Fagonia bruguieri DC.	6.4 to 9.3
Fagonia indica Burm.f.	6.8 to 8.3
Farsetia aegyptia Turra	6.6 to 9.4
Ferocactus flavovirens (Scheidw.) Britton & Rose	7.4 to 7.5
Ferocactus gracilis H.E.Gates	6.2 to 7.7
Flueggea virosa (Roxb. ex Willd.) Royle	7 to 8
Forestiera sp.	7.4 to 7.5
Fouquieria columnaris (C.Kellogg) Kellogg ex Curran	6.2 to 7.7
Fouquieria splendens Engelm.	6.2 to 7.6
Gardenia volkensii K.Schum.	7 to 8
Gastrocotyle hispida (Forssk.) Bunge	6.7 to 9.4
Glinus lotoides L.	5.3 to 8.3
Glycyrrhiza inflata Batalin	6.4 to 9.6
Gomphrena pringlei J.M.Coult. & Fisher	6.1 to 6.9
Gomphrena serrata L.	6.1 to 6.9
Grewia damine Gaertn.	7 to 8
Grewia flavescens Juss.	7 to 8
Grewia villosa Willd.	7 to 8
Gymnosporia senegalensis (Lam.) Loes.	7 to 8
Halimodendron halodendron (Pall.) Voss	6.4 to 10
Halostachys belangeriana (Moq.) Botsch.	6.4 to 9.7
Haloxylon salicornicum (Moq.) Bunge ex Boiss.	7.3 to 8.3
Hechtia sp.	7.2 to 7.5
Hedysarum scoparium Fisch. & C.A.Mey.	7.4 to 7.6
Heliotropium arbainense Fresen.[#]	6.2 to 9.3
Heliotropium bacciferum Forssk.	6.2 to 9.3
Heliotropium luteum Poir.[#]	6.6 to 9.4
Heliotropium ovalifolium Forssk.	7 to 8
Hexinia polydichotoma (Ostenf.) H.L.Yang	6.8 to 7.8
Hibiscus surattensis L.	7 to 8
Hordeum vulgare L.	7.1 to 7.7
Hyphaene coriacea Gaertn.	7 to 8
Ifloga spicata (Forssk.) Sch.Bip.	7.4 to 8.3
Indigofera arrecta A.Rich.	7 to 8
Indigofera filipes Harv.	7 to 8
Indigofera spinosa Forssk.	6.2 to 9.3
Iphiona mucronata (Forssk.) Asch. & Schweinf.	6.7 to 9.2
Ipomoea biflora (L.) Pers.	7 to 8
Ipomoea wolcottiana subsp. wolcottiana	7.4 to 7.5
Jasminum fluminense Vell.	7 to 8
Jatropha cuneata Wiggins & Rollins	7.2 to 8.7
Juncus rigidus Desf.	7.2 to 7.7
Justicia flava (Vahl) Vahl	7 to 8
Karelinia caspia (Pall.) Less.	6.4 to 10
Kochia indica Wight	7.1 to 7.7
Krameria erecta Willd. ex Schult.	6.6 to 7
Krameria grayi Rose & Painter	6.6 to 8.7
Kraussia floribunda Harv.	7 to 8
Kyphocarpa angustifolia (Moq.) Lopr.	7 to 8
Lagenaria siceraria (Molina) Standl.	7 to 8
Lamourouxia rhinanthifolia Kunth	5.1 to 6.8
Lantana camara L.	7 to 8
Larrea tridentata (Sessé & Moc. ex DC.) Coville	6.2 to 8.7
Launaea capitata (Spreng.) Dandy	7.1 to 7.9
Launaea mucronata (Forssk.) Muschl.	7.1 to 8.3
Leonotis nepetifolia (L.) R.Br.	7 to 8
Leptadenia pyrotechnica (Forssk.) Decne.	7.3 to 9.3
Leucophyllum sp.	7.2 to 7.4
Limeum sulcatum (Klotzsch) Hutch.	7 to 8
Lippia graveolens Kunth	6.1 to 7.5
Lippia javanica (Burm.f.) Spreng.	7 to 8
Lolium persicum Boiss. & Hohen.	7.4 to 7.7
Lophocereus schottii (Engelm.) Britton & Rose	6.6 to 8.7
Ludwigia octovalvis (Jacq.) P.H.Raven	7 to 8
Lycium pallidum Miers	8.1 to 8.8
Lycium ruthenicum Murray	6.1 to 10.1
Lycium shawii Roem. & Schult.	7.9 to 9.1
Malva parviflora L.	7.3 to 7.7

Species	pH range
Melhania forbesii Planch. ex Mast.	7 to 8
Melia azedarach L.	7 to 8
Mimosa aculeaticarpa Ortega	5.2 to 6.4
Mimosa adenantheroides (M.Martens & Galeotti) Benth.	5.1 to 6.8
Mimosa borealis A.Gray	5.2 to 6.4
Mimosa calcicola Robinson	7.4 to 7.5
Mimosa lacerata Rose	7.2 to 7.4
Mimosa luisana Brandegee	6.1 to 7.5
Mimosa polyantha Benth.	6.1 to 6.9
Mimosa purpusii Brandegee	7.2 to 7.4
Momordica balsamina L.	7 to 8
Morkillia mexicana (DC.) Rose & Painter	7.4 to 7.5
Myrtillocactus geometrizans (Mart. ex Pfeiff.) Console	7.4 to 7.5
Neobuxbaumia tetetzo (F.A.C.Weber ex K.Schum.) Backeb.	7.4 to 7.5
Nitraria sibirica Pall.	6.4 to 9.8
Nolina longifolia (Karw. ex Schult. & Schult.f.) Hemsl.	7.2 to 7.4
Ochna natalitia (Meisn.) Walp.	7 to 8
Ochradenus baccatus Delile[#]	6.6 to 9.4
Ochthochloa compressa (Forssk.) Hilu	7.7 to 7.9
Oligomeris linifolia (Vahl) J.F. Macbr.	7.1 to 7.8
Olneya tesota A.Gray	6.6 to 8.7
Opuntia decumbens Salm-Dyck	6.1 to 6.9
Opuntia pilifera F.A.C. Weber	6.1 to 7.4
Opuntia streptacantha Lem.	5.1 to 6.8
Opuntia velutina F.A.C. Weber	6.1 to 6.9
Orobanche aegyptiaca Pers.	7.3 to 7.7
Pachycereus pringlei (S.Watson) Britton & Rose	6.6 to 7
Pachycormus discolor (Benth.) Coville	7.3 to 7.7
Panicum repens L.	7.3 to 9.3
Panicum turgidum Forssk.	6.2 to 9.3
Parkinsonia praecox (Ruiz & Pav.) Hawkins	7.4 to 7.5
Paspalum distichum L.	8.5 to 9.5
Pavetta catophylla K.Schum.	7 to 8
Pavetta lanceolata Eckl.	7 to 8
Peganum harmala L.	7.7 to 7.9
Penstemon sp.	5.2 to 6.4
Phalaris minor Retz.	7.4 to 7.7
Philenoptera violacea (Klotzsch) Schrire	7 to 8
Phoenix dactylifera L.	7.1 to 7.6
Phragmites australis (Cav.) Trin. ex Steud.	6.4 to 9.7
Phragmites mauritianus Kunth	7 to 8
Phyllanthus reticulatus Poir.	7 to 8
Piqueria trinervia Cav.	5.2 to 6.4
Plantago boissieri Hausskn. & Bornm. [#]	7.1 to 8.3
Pluchea dioscoridis (L.) DC.	7 to 8
Plumbago zeylanica L.	7 to 8
Plumeria rubra L.	5.1 to 6.8
Poa angustifolia L.	7.4 to 7.6
Polygonum argyrocoleon Steud. ex Kunze	7.3 to 7.8
Populus euphratica Olivier	6.1 to 10.5
Prosopis glandulosa Torr.	6.2 to 7.6
Prosopis juliflora (Sw.) DC.	6.2 to 7.9
Prosopis laevigata (Willd.) M.C.Johnst.	5.1 to 6.8
Psammochloa villosa (Trin.) Bor	7.4 to 7.6
Pseudosmodingium multifolium Rose	7.4 to 7.5
Pulicaria crispa Sch.Bip.	6.6 to 9.4
Randia capitata DC.	5.2 to 6.4
Reichardia tingitana (L.) Roth	6.6 to 9.4
Rhanterium epapposum Oliv.	7.5 to 8.3
Ruellia patula Jacq.	7 to 8
Salsola baryosma (Schult.) Dandy	7.2 to 7.7
Salsola kali L.	7.4 to 9.7
Salsola pellucida Litv.	7.4 to 9
Salsola schweinfurthii Solms	7.2 to 8.2
Salvadora persica L. [#]	6.2 to 9.7
Sarcobatus vermiculatus (Hook.) Torr.	9.6 to 9.7
Schismus barbatus (L.) Thell.	7.1 to 7.7
Schmidtia pappophoroides Steud. ex J.A.Schmidt	7 to 8
Schoenoplectiella roylei (Nees) Lye	8.1 to 8.5
Senecio flavus (Decne.) Sch.Bip.	7.3 to 7.6
Senecio praecox (Cav.) DC.	5.2 to 6.4
Senna alexandrina Mill.	7.9 to 9.1
Senna holosericea (Fresen.) Greuter	7 to 7.6

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Species	pH range
Senna italica Mill.	6.2 to 8.6
Senna occidentalis (L.) Link	7 to 8
Senna uniflora (Mill.) H.S.Irwin & Barneby	5.1 to 6.8
Sesamum alatum Thonn.	7 to 8
Sida cordifolia L.	7 to 8
Sida spinosa L.	7 to 8
Simmondsia chinensis (Link) C.K. Schneid.	6.2 to 8
Solanum carolinense L. #	7 to 8
Solanum seaforthianum Andrews	7 to 8
Sonchus oleraceus (L.) L.	7.3 to 8.1
Sorghum bicolor (L.) Moench	7 to 8
Spirostachys africana Sond.	7 to 8
Sporobolus ioclados (Trin.) Nees	9 to 9.5
Sporobolus pyramidalis P.Beauv.	7 to 8
Sporobolus spicatus (Vahl) Kunth	6.2 to 9.7
Sporobolus virginicus (L.) Kunth	6.3 to 8.7
Stenocereus pruinosus (Otto ex Pfeiff.) Buxb.	6.1 to 6.9
Stenocereus stellatus (Pfeiff.) Riccob.	5.1 to 6.8
Stenocereus thurberi (Engelm.) Buxb.	6.6 to 8.7
Stipa caucasica Schmalh.	7.4 to 7.6
Stipa speciosa Trin. & Rupr.	6.6 to 7
Stipagrostis ciliata (Desf.) De Winter	7.3 to 8.3
Stipagrostis plumosa Munro ex T.Anderson	6.2 to 8.5
Suaeda fruticosa Forssk. ex J.F.Gmel.	5.8 to 8.3
Suaeda monoica Forssk. #	6.2 to 9.7
Suaeda vermiculata Forssk. ex J.F.Gmel.	7.1 to 7.7
Tagetes minuta L.	7 to 8
Tamarix aphylla (L.) H.Karst.	6.3 to 9.7
Tamarix hispida Willd.	6.4 to 9.7
Tamarix leptostachya Bunge	6.4 to 10
Tamarix mannifera Kotschy ex Bunge#	6.3 to 9.7
Tamarix ramosissima Ledeb.	6.1 to 10.5
Taraxacum mongolicum Hand.-Mazz.	7.7 to 8.4
Tecoma stans (L.) Juss. ex Kunth	5.1 to 6.8
Tephrosia purpurea (L.) Pers.	6.2 to 9.3
Terminalia sericea Burch. ex DC.	7 to 8
Tetraena qatarensis (Hadidi) Beier & Thulin. #	7.1 to 8.3
Themeda triandra Forssk.	7 to 8
Thunbergia neglecta Sond. #	7 to 8
Tragus australianus S.T.Blake	7 to 8
Trema orientalis (L.) Blume	7 to 8
Tribulus arabicus Hosni#	7.5 to 8.3
Tribulus terrestris L.	7 to 8
Tricholaena monachne (Trin.) Stapf & C.E.Hubb.	7 to 8
Tridax procumbens (L.) L.	7 to 8
Triumfetta bogotensis DC.	7 to 8
Urochloa mosambicensis (Hack.) Dandy	7 to 8
Vangueria infausta Burch.	7 to 8
Verbena litoralis var. brasiliensis	7 to 8
Vernonia glabra (Steetz) Vatke	7 to 8
Vitex harveyana H.Pearson	7 to 8
Waltheria indica L.	7 to 8
Xanthium strumarium	7 to 8
Yucca periculosa Baker	7.2 to 7.4
Zapoteca sp.	7.4 to 7.5
Zilla spinosa (L.) Prantl#	6.6 to 9.4
Ziziphus spina-christi (L.) Willd.	7.3 to 9.3
Zygophyllum coccineum L. #	6.6 to 9.4
Zygophyllum simplex L.	6.6 to 9.4
(g) Mediterranean forest, woodland, and scrub	
Aegilops neglecta Req. ex Bertol.	6.5 to 6.7
Atractylis humilis L.	8 to 8.3
Aulax umbellata (Thunb.) R.Br.	5.3 to 5.6
Bellis sylvestris Cirillo	6.4 to 6.7
Brachypodium retusum (Pers.) P.Beauv.	6.5 to 8
Bromus rubens L.	6.5 to 8.3
Buxus sempervirens L.	7.4 to 8.5
Calopsis hyalina (Mast.) H.P.Linder	5.4 to 5.6
Dactylis glomerata L.	6.5 to 6.7
Echinospartum horridum (M.Vahl) Rothm.	7.4 to 8.5
Elegia verreauxii Mast.	4.9 to 5.5
Erica labialis Salisb.	5.4 to 5.5

Species	pH range
Erica lutea P.J.Bergius	5.4 to 5.5
Genista scorpius (L.) DC.	7.4 to 8.5
Ischyrolepis leptoclados (Mast.) H.P.Linder	7.7 to 7.8
Juniperus communis L.	7.4 to 8.5
Leucadendron meridianum T.M.Salter ex I.Williams[#]	7.7 to 7.9
Leucadendron xanthoconus K. Schum.	5.4 to 5.9
Linum strictum L.	6.5 to 6.7
Metalasia muricata (L.) D.Don	5.9 to 6.2
Mimetes cucullatus R. Br.	4.9 to 5.5
Mimetes saxatilis E.Phillips[#]	7.8 to 7.9
Pinus sylvestris L.	7.4 to 8.5
Populus nigra L.	6.4 to 8.6
Populus tremula L.	6.4 to 8.6
Protea compacta R. Br.	5.4 to 5.7
Protea susannae E.Phillips[#]	5.4 to 6.2
Quercus faginea Lam.	6.4 to 8.6
Santolina chamaecyparissus L.	8 to 8.3
Senecio vulgaris L.	6.5 to 6.7
Willdenowia rugosa Esterh.	5.9 to 6.1

(h) Temperate broadleaf mixed forest

Species	pH range
Acalypha virginica var. rhomboidea	3.9 to 4.4
Acer campestre L.	3.3 to 8.7
Acer negundo L.	5.9 to 7.8
Acer pensylvanicum L.	4.1 to 5.9
Acer platanoides L.	3.1 to 6.4
Acer pseudoplatanus L.	2.4 to 8.7
Acer rubrum L.	3.3 to 6.9
Acer saccharinum L.	6.6 to 7.8
Acer saccharum Marshall	3.6 to 8.2
Acer saccharum subsp. nigrum (F.Michx.) Desmarais	4.7 to 5.1
Acer spicatum Lam.	4.1 to 5.9
Achillea millefolium L.	3.1 to 9.2
Actaea racemosa L.	3.8 to 4.5
Adiantum pedatum L.	4.2 to 5.1
Adoxa moschatellina L.	3.1 to 8
Aegonychon purpurea-coeruleum Holub.	3.3 to 6.3

Species	pH range
Aegopodium podagraria L.	4.5 to 6.3
Aesculus hippocastanum L.	3.1 to 6.2
Ageratina altissima (L.) R.M.King & H.Rob.	3.8 to 5.1
Agrostis canina L.	2.9 to 6.4
Agrostis capillaris L.	2.9 to 6.3
Agrostis curtisii Kerguélen	4.2 to 5.6
Agrostis stolonifera L.	3.4 to 9.4
Agrostis vinealis Schreb.	4.2 to 5.8
Aira praecox L.	4.3 to 6
Ajuga pyramidalis L.	4 to 7.2
Ajuga reptans L.	3.1 to 6.4
Alliaria petiolata (M.Bieb.) Cavara & Grande	3.1 to 8.4
Allium oleraceum L.	4.5 to 5.1
Allium tricoccum Sol.	4.7 to 5.1
Alnus glutinosa (L.) Gaertn.	4.1 to 6
Alnus incana (L.) Moench	3.5 to 4.1
Alopecurus geniculatus L.	6.2 to 9.2
Alopecurus pratensis L.	5.8 to 6.6
Ambrosia artemisiifolia L.	5.3 to 5.5
Amelanchier arborea (F. Michx.) Fernald	3.8 to 4.5
Amphicarpaea bracteata (L.) Fernald	3.8 to 4.5
Anemone hepatica L.	4.7 to 6.1
Anemone nemorosa L.	3.1 to 8.7
Anemone sylvestris L.	4.1 to 4.5
Anemonella thalictroides (L.) Spach	3.8 to 4.5
Angelica sylvestris L.	4.9 to 6.6
Antennaria dioica (L.) Gaertn.	3.1 to 5.8
Anthericum ramosum L.	4 to 7.3
Anthoxanthum odoratum L.	2.9 to 7.2
Anthriscus sylvestris (L.) Hoffm.	4.5 to 7.7
Arabidopsis thaliana (L.) Heynh.	4.2 to 5.2
Arabis hirsuta (L.) Scop.	4.1 to 4.5
Aralia nudicaulis L.	4.4 to 4.8
Arisaema triphyllum (L.) Schott	3.8 to 5.1
Aristolochia serpentaria L.	3.8 to 4.5
Arnica montana L.	3.1 to 5.9
Arrhenatherum elatius (L.) P.Beauv. ex J.Presl & C.Presl.	4.8 to 7.8

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Species	pH range
Artemisia vulgaris L.	6.2 to 9.2
Arthraxon hispidus (Thunb.) Makino	3.9 to 4.4
Arum cylindraceum Gasp.	6.5 to 7.5
Arum maculatum L.	3.1 to 8.7
Asarum canadense L.	4.2 to 5.1
Asarum europaeum L.	4.6 to 4.8
Asplenium platyneuron (L.) Britton, Sterns & Poggenb.	5.3 to 5.5
Asplenium trichomanes L.	4.7 to 8.7
Aster sp.	4.7 to 5.1
Astragalus glycyphyllos L.	3.7 to 4.4
Athyrium filix-femina (L.) Roth	3.1 to 6.3
Atriplex patula L.	6.4 to 8.9
Atriplex prostrata Boucher ex DC.	6.1 to 9.3
Atriplex sagittata Borkh.	6.2 to 9.2
Atropa belladonna L.	5.2 to 8.4
Avena sativa L.	6.2 to 9.2
Betula alleghaniensis Britton	4.1 to 5.9
Betula lenta L.	3.3 to 5.2
Betula nigra L.	6.6 to 7.8
Betula papyrifera Marshall	3.6 to 5.9
Betula pendula Roth	3.1 to 7.9
Betula populifolia Marshall	3.4 to 4.1
Betula pubescens Ehrh.	2.9 to 6
Bidens tripartita L.	6.2 to 9.2
Bolboschoenus maritimus (L.) Palla	4.5 to 9.3
Bossekia odorata (L.) Greene	4.7 to 5.1
Botrychium virginianum (L.) Sw.	3.8 to 5.1
Brachyelytrum erectum (Schreb.) P.Beauv.	3.8 to 4.5
Brachypodium pinnatum (L.) P.Beauv.	4 to 7.8
Brachypodium sylvaticum (Huds.) P.Beauv.	3.3 to 8.4
Brassica napus L.	6.2 to 9.2
Briza media L.	4.3 to 5.9
Bromus benekenii (Lange) Trimen	3.3 to 7.3
Bromus ramosus Huds.	5.2 to 8.4
Bromus sterilis L.	5.6 to 6.5
Buddleja davidii Franch.	4.7 to 5.2
Calamagrostis arundinacea (L.) Roth	3.3 to 6.5
Calamagrostis epigeios (L.) Roth	4.3 to 7.9
Calamagrostis villosa (Chaix) J.F.Gmel.	3.5 to 6.2
Callionia canadensis (L.) Greene	3.8 to 4.5
Calluna vulgaris (L.) Hull	2.9 to 5.9
Caltha palustris L.	6.7 to 8.3
Calystegia sepium (L.) R. Br.	4.6 to 5.3
Campanula persicifolia L.	3.7 to 7.3
Campanula rapunculoides L.	3.3 to 6.3
Campanula rotundifolia L.	3.1 to 6.5
Campanula trachelium L.	5.1 to 8.7
Cardamine concatenata (Michx.) O.Schwarz	4.7 to 5.1
Cardamine diphylla (Michx.) Alph.Wood	4.7 to 5.1
Cardamine flexuosa With.	5.1 to 6.6
Cardamine maxima (Nutt.) Alph.Wood	4.7 to 5.1
Cardamine pratensis L.	3.1 to 6.6
Carex albursina E.Sheld.	4.7 to 5.1
Carex appalachica J.M.Webber & P.W.Ball	4.7 to 5.1
Carex arenaria L.	4.4 to 5.8
Carex brizoides L.	4.3 to 4.4
Carex caryophyllea Latourr.	4.3 to 5.9
Carex communis L.H.Bailey	4.7 to 5.1
Carex cuprina (Sándor ex Heuff.) Nendtv. ex A.Kern.	6.2 to 8.6
Carex digitalis Willd.	3.8 to 4.5
Carex digitata L.	3.7 to 5.9
Carex distans L.	6.2 to 8.6
Carex echinata Murray	4.1 to 5.3
Carex flacca Schreb.	4.3 to 8
Carex frankii Kunth	3.9 to 4.4
Carex hirta L.	3.7 to 6.3
Carex hitchcockiana Dewey	4.7 to 5.1
Carex hostiana DC.	3.1 to 6.4
Carex humilis Leyss.	3.7 to 4.5
Carex laxiflora Lam.	4.7 to 5.1
Carex leporina L.	3.1 to 6
Carex montana L.	3.7 to 7.3
Carex muricata L.	3.5 to 7.3

Species	pH range
Carex nigra (L.) Reichard	2.5 to 6.4
Carex pallescens L.	4 to 6
Carex panicea L.	3.1 to 6.4
Carex pedunculata Muhl. ex Willd.	4.7 to 5.1
Carex pendula Huds.	4.9 to 8.4
Carex pensylvanica Lam.	3.4 to 4.1
Carex pilulifera L.	2.9 to 7
Carex pilulifera subsp. pilulifera	4.1 to 6.4
Carex plantaginea Lam.	4.7 to 5.1
Carex platyphylla J.Carey	4.7 to 5.1
Carex pseudocyperus L.	4.7 to 5.2
Carex remota L.	3.1 to 6.3
Carex riparia subsp. riparia	3.8 to 4.5
Carex spicata Huds.	5.2 to 8.4
Carex sylvatica Huds.	3.1 to 8.7
Carex tribuloides Wahlenb.	3.9 to 4.4
Carex vulpinoidea Michx.	3.9 to 4.4
Carex willdenowii Willd.	3.8 to 4.5
Carpinus betulus L.	2.4 to 8
Carpinus caroliniana Walter	3.8 to 5.5
Carya alba (L.) Nutt. ex Elliott	4.5 to 8
Carya cordiformis (Wangenh.) K.Koch	3.8 to 5.1
Carya glabra (Mill.) Sweet	3.8 to 4.9
Carya glabra var. odorata	4.3 to 4.9
Carya texana Buckley	4.5 to 8
Castanea sativa Mill.	3.1 to 5.5
Caulophyllum thalictroides (L.) Michx.	4.2 to 5.1
Celtis occidentalis L.	6.6 to 7.8
Centaurea jacea L.	2.9 to 5.9
Centaurea scabiosa L.	6 to 6.9
Centaurea stoebe L.	6.2 to 9.2
Centaurium erythraea Rafn	4.7 to 5.2
Cephalanthera damasonium (Mill.) Druce	5.2 to 8.4
Cerastium fontanum Baumg.	3.1 to 6
Cerastium fontanum subsp. vulgare (Hartm.) Greuter & Burdet.	6.2 to 9.2
Cercis canadensis L.	3.8 to 8.2
Chaerophyllum hirsutum L.	4.9 to 5.8
Chaerophyllum temulum L.	3.3 to 8
Chelidonium majus L.	5.1 to 5.3
Chenopodium album L.	6.2 to 9.2
Chenopodium glaucum L.	6.2 to 9.2
Chenopodium polyspermum L.	4.7 to 8.4
Chenopodium rubrum L.	5.2 to 8.6
Chimaphila maculata (L.) Pursh	3.8 to 4.5
Chrysosplenium oppositifolium L.	3.1 to 5.5
Cinna arundinacea L.	3.9 to 4.4
Circaea lutetiana L.	3.1 to 8.4
Cirsium arvense (L.) Scop.	5.1 to 9.3
Cirsium dissectum (L.) Hill	3.1 to 6.4
Cirsium palustre (L.) Coss. ex Scop.	4.7 to 6.4
Claytonia caroliniana Michx.	4.7 to 5.1
Claytonia virginica L.	3.8 to 4.5
Clematis recta L.	4.1 to 4.5
Clinopodium vulgare L.	3.3 to 6.3
Comarum palustre L.	4.7 to 6.4
Commelina communis L.	3.9 to 6.4
Conopodium majus (Gouan) Loret	5.1 to 6.6
Convallaria majalis L.	3.1 to 6.8
Convolvulus arvensis L.	6.5 to 8.9
Conyza canadensis (L.) Cronquist	6.2 to 9.2
Cornus alternifolia L.f.	4.5 to 8.2
Cornus florida L.	3.8 to 6.1
Cornus mas L.	4 to 4.5
Cornus sanguinea L.	3.3 to 8.7
Corydalis intermedia (L.) Mérat	4.8 to 8
Corylus avellana L.	3.1 to 8.7
Corynephorus canescens (L.) P.Beauv.	4.4 to 5.8
Cotoneaster integerrimus Medik.	4 to 4.5
Crataegus laevigata (Poir.) DC.	2.6 to 8.7
Crataegus monogyna Jacq.	3.1 to 8.7
Cunila origanoides (L.) Britton	3.8 to 4.2
Cyperus strigosus L.	3.9 to 4.4
Cystopteris bulbifera (L.) Bernh.	4.7 to 5.1
Cystopteris fragilis (L.) Bernh.	4.7 to 5.1

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Species	pH range
Cytisus scoparius (L.) Link	2.9 to 5.6
Daboecia cantabrica (Huds.) K.Koch	4.2 to 5.6
Dactylis glomerata L.	2.5 to 8
Dactylorhiza maculata (L.) Soó	2.9 to 6.4
Danthonia decumbens (L.) DC.	2.9 to 6.4
Danthonia spicata (L.) Roem. & Schult.	3.8 to 5.6
Daphne mezereum L.	5.5 to 8.7
Daucus carota L.	4.3 to 5.9
Dennstaedtia punctilobula (Michx.) T. Moore	4.7 to 5.1
Deparia acrostichoides (Sw.) M. Kato	4.7 to 5.1
Deschampsia cespitosa (L.) P.Beauv.	2.4 to 8.9
Deschampsia flexuosa (L.) Trin.	2.9 to 6.3
Desmodium glutinosum (Willd.) Alph.Wood	3.8 to 4.5
Desmodium nudiflorum (L.) DC.	3.8 to 4.5
Desmodium paniculatum (L.) DC.	5.3 to 5.5
Dicentra sp.	4.7 to 5.1
Dictamnus albus L.	4.1 to 4.5
Diervilla lonicera Mill.	4.4 to 5.6
Digitalis purpurea L.	4.2 to 5.6
Digitaria sanguinalis (L.) Scop.	3.9 to 4.4
Diodia virginiana L.	3.9 to 4.4
Dioscorea villosa L.	3.8 to 4.5
Diospyros virginiana L.	5.3 to 5.5
Drosera intermedia Hayne	3.9 to 5.4
Drosera rotundifolia L.	3.9 to 5.4
Dryopteris carthusiana (Vill.) H.P. Fuchs	2.4 to 6.3
Dryopteris dilatata (Hoffm.) A. Gray	2.4 to 5.5
Dryopteris filix-mas (L.) Schott	3.1 to 8.7
Dryopteris goldiana (Hook. ex Goldie) A. Gray	4.7 to 5.1
Dryopteris intermedia (Muhl. ex Willd.) A. Gray	4.7 to 5.1
Dryopteris marginalis (L.) A. Gray	4.7 to 5.1
Eleocharis multicaulis (Sm.) Desv.	4.1 to 5.3
Elephantopus carolinianus Raeusch.	3.9 to 4.4
Elymus caninus (L.) L.	3.3 to 7.7
Elymus hystrix L.	4.7 to 5.1
Elymus repens (L.) Gould	6.1 to 9.3
Empetrum nigrum L.	3.1 to 5.6
Epilobium angustifolium L.	3.1 to 6.3
Epilobium hirsutum L.	5.1 to 5.9
Epilobium montanum L.	4.4 to 5.5
Epilobium palustre L.	6.2 to 9.2
Equisetum palustre L.	2.9 to 6.4
Equisetum sylvaticum L.	4.3 to 5.8
Erica tetralix L.	2.9 to 6.4
Eriophorum angustifolium Honck.	3.1 to 5.6
Erythronium americanum Ker Gawl.	4.7 to 5.1
Euonymus europaeus L.	4.1 to 8.7
Euphorbia amygdaloides L.	3.3 to 8.4
Euphorbia cyparissias L.	4 to 4.4
Eurybia divaricata (L.) G.L.Nesom	3.8 to 5.1
Eurybia macrophylla (L.) Cass.	5.5 to 5.6
Fagus grandifolia Ehrh.	3.3 to 6.9
Fagus sylvatica L.	3.1 to 7.9
Fallopia cilinodis (Michx.) Holub	4.6 to 5.1
Fallopia convolvulus (L.) Á.Löve	3.3 to 6.6
Festuca arundinacea Schreb.	6.2 to 8.6
Festuca arundinacea var. spuria	3.9 to 4.4
Festuca gigantea (L.) Vill.	4.4 to 6.6
Festuca heterophylla Lam.	3.7 to 7.3
Festuca ovina L.	2.9 to 7.3
Festuca pratensis Huds.	6.2 to 9.2
Festuca rubra L.	2.9 to 9.3
Festuca rupicola Heuff.	4.1 to 7.7
Ficaria verna Huds.	3.1 to 8.7
Filipendula rubra (Hill) B.L. Rob.	5.5 to 6.9
Filipendula ulmaria (L.) Maxim.	3.7 to 6.6
Fragaria vesca L.	3.7 to 8.7
Fragaria virginiana Duchesne	4.4 to 4.6
Fragaria viridis Duch. [#]	3.3 to 7.3
Frangula dodonei Ard.	2.4 to 8
Fraxinus americana L.	3.8 to 8.2
Fraxinus excelsior L.	3.1 to 8.4
Fraxinus pennsylvanica Marshall	6.6 to 7.8

Species	pH range
Gagea lutea (L.) Ker Gawl.	4.1 to 7.5
Galeopsis bifida Boenn.	2.4 to 7.3
Galeopsis tetrahit L.	3.1 to 6.6
Galium aparine L.	3.1 to 8
Galium boreale L.	4 to 7.3
Galium circaezans Michx.	3.8 to 4.5
Galium concinnum Torr. & A.Gray	4.2 to 4.5
Galium odoratum (L.) Scop.	3.2 to 8.7
Galium palustre L.	4.7 to 6.4
Galium saxatile L.	2.9 to 5.9
Galium saxatile var. saxatile	3.5 to 6
Galium sylvaticum L.	3.7 to 7.3
Galium triflorum Michx.	3.8 to 5.1
Galium uliginosum L.	4.7 to 6.4
Galium verum L.	4.3 to 5.9
Gaultheria procumbens L.	3.4 to 5.6
Gaylussacia baccata (Wangenh.) K.Koch	3.5 to 6
Genista anglica L.	2.9 to 5.9
Genista pilosa L.	2.9 to 5.8
Gentiana pneumonanthe L.	3.1 to 6.4
Geranium columbinum L.	4.2 to 5.2
Geranium maculatum L.	3.8 to 4.5
Geranium robertianum L.	3.1 to 8.4
Geranium sylvaticum L.	4.5 to 6.3
Geum canadense Jacq.	4.7 to 5.1
Geum urbanum L.	3.1 to 8.4
Glandora prostrata (Loisel.) D.C.Thomas	4.2 to 5.6
Glechoma hederacea L.	3.1 to 8.4
Grossularia cynosbati (L.) Mill. [#]	4.7 to 5.1
Gymnocarpium dryopteris (L.) Newman	4.2 to 6
Halimium alyssoides K.Koch[#]	4.2 to 5.6
Hamamelis virginiana L.	3.8 to 4.5
Hedera helix L.	3.1 to 8.7
Helianthus divaricatus L.	3.8 to 4.5
Helictotrichon pubescens (Huds.) Schult. & Schult.f.	4.7 to 5.1
Hepatica nobilis Mill.	3.7 to 7.7
Heracleum sphondylium L.	3.1 to 6.6
Hieracium lachenalii	3.7 to 7.3
Hieracium maculatum Schrank	3.7 to 4.2
Hieracium murorum L.	2.5 to 7.3
Hieracium pilosella L.	2.9 to 6.2
Hieracium piloselloides Vill.	4.7 to 5.6
Hieracium sabaudum L.	3.1 to 6.5
Hieracium tridentatum (Fr.) Fr.	4.5 to 5.1
Hieracium umbellatum L.	2.5 to 5.9
Hieracium vulgatum Fr.	4.8 to 5.1
Hierochloe australis (Schrad.) Roem. & Schult.	3.7 to 4.2
Holcus lanatus L.	2.9 to 7.2
Holcus mollis L.	2.9 to 6.3
Hordelymus europaeus (L.) Jess. ex Harz	3.3 to 5.5
Hordeum vulgare L.	6.2 to 9.2
Hyacinthoides non-scripta (L.) Chouard ex Rothm.	5.1 to 6.6
Hydrangea arborescens L.	3.8 to 4.5
Hydrocotyle vulgaris L.	3.9 to 6.4
Hydrophyllum virginianum L. [#]	4.6 to 5.1
Hypericum hirsutum L.	3.3 to 8.4
Hypericum humifusum L.	4.7 to 5.2
Hypericum maculatum Crantz	4.5 to 5.1
Hypericum perforatum L.	3.3 to 8.4
Hypericum pulchrum L.	3.1 to 6.3
Hypochaeris maculata L.	4.5 to 5.1
Hypochoeris radicata L.	4 to 4.4
Ilex aquifolium L.	3.1 to 6.3
Impatiens noli-tangere L.	4.6 to 4.8
Impatiens parviflora DC.	3.3 to 7.7
Jasione montana L.	4.4 to 5.8
Juglans nigra L.	5.9 to 6.1
Juncus acutiflorus Ehrh. ex Hoffm.	3.9 to 6.4
Juncus alpinoarticulatus Chaix	4.7 to 6.4
Juncus articulatus L.	4.7 to 8.3
Juncus bufonius L.	4.7 to 6.6
Juncus bulbosus L.	4.1 to 5.3
Juncus compressus Jacq.	6.1 to 9.3
Juncus conglomeratus L.	3.1 to 6.4

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Species	pH range
Juncus effusus L.	2.9 to 8.4
Juncus squarrosus L.	2.9 to 5.9
Juncus tenuis Willd.	3.9 to 4.4
Juniperus communis L.	4.1 to 4.6
Juniperus virginiana L.	5.8 to 8
Knautia maxima (L.) Coult.	3.1 to 5.9
Kummerowia stipulacea (Maxim.) Makino	5.3 to 5.5
Lactuca serriola L.	6.1 to 9.3
Lamium purpureum L.	5.7 to 7.2
Laportea canadensis (L.) Wedd.	4.2 to 5.1
Lapsana communis L.	4.5 to 8.4
Larix decidua Mill.	3.5 to 6
Lathyrus linifolius (Reichard) Bassler	4 to 5.5
Lathyrus niger (L.) Bernh.	3.7 to 7.3
Lathyrus pratensis L.	4.5 to 7.7
Lathyrus vernus (L.) Bernh.	3.7 to 7.7
Lembotropis nigricans (L.) Griseb.	4 to 6.5
Leontodon autumnalis L.	6.2 to 8.6
Leontodon hispidus L.	4.3 to 5.9
Lepidium ruderale L.	6.2 to 9.2
Ligustrum vulgare L.	3.3 to 6.3
Lilium martagon L.	7 to 7.7
Lindera benzoin (L.) Blume	3.8 to 4.5
Linum catharticum L.	4.3 to 5.9
Liquidambar styraciflua L.	5.3 to 5.5
Liriodendron tulipifera L.	3.3 to 8.2
Lobelia siphilitica L.	5.3 to 5.5
Lolium perenne L.	5.8 to 8.1
Lonicera japonica[#]	2.4 to 8.7
Lonicera oblata[#]	7 to 7.7
Lonicera xylosteum Thunb.	5.3 to 6.6
Lotus corniculatus L.	4.2 to 5.9
Lotus maritimus L.	6.2 to 8.6
Lotus pedunculatus Cav.	4.7 to 6.4
Lotus tenuis Waldst. & Kit.	6.2 to 8.6
Luzula campestris (L.) DC.	2.5 to 6.4
Luzula forsteri (Sm.) DC.	4.8 to 5.1
Luzula luzuloides (Lam.) Dandy & Wilmott	4 to 6.5
Luzula multiflora (Ehrh.) Lej.	2.9 to 6.2
Luzula multiflora subsp. multiflora	5.8 to 6
Luzula pilosa (L.) Willd.	3.1 to 8.4
Lycopodiella inundata (L.) Holub	3.9 to 5.4
Lycopodium clavatum L.	3.8 to 4.9
Lysimachia maritima (L.) Galasso, Banfi & Soldano	3.4 to 9.4
Lysimachia nemorum L. [#]	3.1 to 5.5
Lysimachia nummularia L. [#]	3.9 to 4.4
Lysimachia vulgaris L.	3.1 to 6.4
Lythrum salicaria L.	4.7 to 6.4
Maianthemum bifolium (L.) F.W.Schmidt	3.1 to 6.3
Maianthemum canadense Desf.	3.4 to 5.1
Maianthemum racemosum (L.) Link	3.8 to 5.1
Malus sylvestris Mill.	3.7 to 5
Matricaria matricarioides (Less.) Porter	5.8 to 6.6
Medicago lupulina L.	6.2 to 8.6
Melampyrum cristatum L. [#]	4 to 4.4
Melampyrum nemorosum L.	5.1 to 5.7
Melampyrum pratense L.	3.7 to 7.3
Melampyrum sylvaticum L. [#]	4.7 to 4.8
Melica nutans L.	3.3 to 8.9
Melica uniflora Retz.	3.1 to 8.7
Melilotus dentatus (Waldst. & Kit.) Pers.	6.2 to 8.6
Melittis melissophyllum L.	3.3 to 6.3
Mentha aquatica L.	4.7 to 8.3
Mercurialis perennis L.	3.3 to 8.4
Microstegium vimineum (Trin.) A.Camus	5.3 to 6.1
Milium effusum L.	3.1 to 8.7
Mitchella repens L.	4.4 to 4.6
Mitella diphylla L. [#]	4.7 to 5.1
Moehringia trinervia (L.) Clairv.	3.1 to 7.7
Molinia caerulea (L.) Moench	2.4 to 6.4
Monarda fistulosa L.	3.8 to 4.5
Morus rubra L.	5.9 to 6.1
Mycelis muralis (L.) Dumort.	3.3 to 7.3

Species	pH range
Myosotis sylvatica Ehrh. ex Hoffm.	6.2 to 7.5
Nardus stricta L.	2.9 to 5.9
Narthecium ossifragum (L.) Huds.	3.9 to 6.4
Neottia nidus-avis (L.) Rich.	5.5 to 8.7
Neottia ovata (L.) Bluff & Fingerh.	5.5 to 6.4
Nyssa sylvatica Marshall	3.8 to 4.5
Odontites vulgaris Moench	6.2 to 8.6
Orchis mascula (L.) L.	5.5 to 8.7
Orchis purpurea Huds.	5.5 to 8.7
Ornithogalum umbellatum L.	5.5 to 6.4
Ornithopus perpusillus L.	4.4 to 5.8
Oryzopsis asperifolia Michx.	4.4 to 5.6
Oryzopsis racemosa (Sm.) Ricker ex Hitchc.	4.7 to 5.1
Osmorhiza aristata (Thunb.) Rydb.	4.6 to 5.1
Ostrya virginiana (Mill.) K.Koch	3.6 to 5.9
Oxalis acetosella L.	3.1 to 6.6
Oxalis corniculata L.	3.9 to 4.4
Oxalis stricta L.	3.9 to 4.4
Oxydendrum arboreum (L.) DC.	3.3 to 5.3
Padus avium var. avium	4.2 to 5
Panax quinquefolius L.	4.7 to 5.1
Panicum anceps Michx.	3.9 to 4.4
Panicum boscii Poir.	3.8 to 4.5
Panicum dichotomum L.	3.8 to 4.5
Paris quadrifolia L.	3.1 to 8
Parnassia palustris Parnassia palustris L.	4.7 to 6.4
Parthenocissus quinquefolia (L.) Planch.	3.8 to 5.1
Pedicularis canadensis L.	4.7 to 4.8
Pedicularis nodosa Pennell[#]	2.9 to 6.4
Pennisetum glaucum (L.) R.Br.	3.9 to 4.4
Persicaria amphibia (L.) Delarbre	6.7 to 8.3
Persicaria bistorta (L.) Samp.	3.1 to 6.3
Persicaria hydropiperoides (Michx.) Small	3.9 to 4.4
Persicaria lapathifolia (L.) Delarbre	6.2 to 9.2
Persicaria maculosa Gray	4 to 8.4
Persicaria pensylvanica (L.) M. Gómez	3.9 to 4.4
Persicaria virginiana (L.) Gaertn.	5.9 to 6.1
Phalaris arundinacea L.	4.8 to 8.6
Phaseolus polystachios (L.) Britton & al.	3.9 to 4.4
Phegopteris hexagonoptera (Michx.) Fée	3.8 to 4.5
Phleum pratense L.	4.7 to 5.1
Phragmites australis (Cav.) Trin. ex Steud.	3.1 to 9.4
Phyteuma spicatum L.	4.3 to 8
Picea abies (L.) H.Karst.	3.5 to 6.9
Pilea pumila (L.) A. Gray	3.8 to 4.5
Pimpinella saxifraga L.	4.3 to 5.9
Pinus banksiana Lamb.	4 to 4.8
Pinus echinata Mill.	4.5 to 8
Pinus resinosa Aiton	3.7 to 4.8
Pinus rigida Mill.	3.4 to 4.1
Pinus strobus L.	3.4 to 8.2
Pinus sylvestris L.	3.6 to 6.5
Plantago intermedia DC.	3.4 to 9.4
Plantago lanceolata L.	2.9 to 6.4
Plantago major L.	5.2 to 9.2
Platanus occidentalis L.	6.6 to 7.8
Poa angustifolia L.	3.3 to 9.2
Poa annua L.	5.1 to 6.6
Poa cuspidata Nutt.	3.8 to 4.5
Poa nemoralis L.	3.1 to 8.7
Poa pratensis L.	2.9 to 7.3
Poa trivialis L.	3.1 to 8.9
Polycodium stamineum (L.) Greene	3.8 to 4.5
Polygala serpyllifolia Hosé	3.1 to 5.9
Polygala vulgaris L.	4.3 to 5.9
Polygonatum biflorum (Walter) Elliott	3.8 to 4.8
Polygonatum multiflorum (L.) All.	3.1 to 8.7
Polygonatum odoratum (Mill.) Druce	4 to 5.4
Polygonatum pubescens (Willd.) Pursh	4.7 to 5.1
Polygonatum verticillatum (L.) All.	4.5 to 4.9
Polygonum aviculare L.	6.2 to 9.2
Polypodium vulgare L.	4.5 to 5.5
Polystichum acrostichoides (Michx.) Schott	3.8 to 5.1
Populus alba L.	3.1 to 5.5

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Species	pH range
Populus tremula L.	3.1 to 7.2
Populus tremula subsp. grandidentata (Michx.) Á. Löve & D. Löve	3.3 to 5.6
Potentilla anserina L.	4.7 to 9.3
Potentilla argentea L.	4.2 to 5.2
Potentilla erecta (L.) Raeusch.	2.9 to 6.4
Potentilla reptans L.	6.7 to 8.3
Potentilla sterilis (L.) Garcke	3.1 to 8.7
Prenanthes sp.	4.7 to 5.1
Primula scandinavica Brunn[#]	3.1 to 8.4
Primula veris L.	4 to 8.4
Prunus avium (L.) L.	3.1 to 7.7
Prunus serotina Ehrh.	3.1 to 8.2
Prunus spinosa L.	3.7 to 8.7
Pseuderanthemum longifolium (G. Forst.) Guilaumin	4.2 to 5.6
Pteridium aquilinum (L.) Kuhn	2.4 to 6.3
Puccinellia distans (Jacq.) Parl.	3.4 to 9.4
Pulmonaria obscura Dumort. [#]	3.7 to 5
Pulmonaria officinalis L. [#]	4.5 to 5.4
Pyrethrum corymbosum (L.) Scop.	3.7 to 7.3
Pyrus pyraster (L.) Du Roi	4 to 4.4
Quercus alba L.	3.4 to 8.2
Quercus coccinea Münchh.	3.8 to 4.5
Quercus ellipsoidalis E.J.Hill	4.4 to 4.8
Quercus ilicifolia Wangenh.	3.7 to 3.8
Quercus marilandica (L.) Münchh.	4.5 to 8
Quercus michauxii Nutt.	3.8 to 8.2
Quercus muehlenbergii Engelm.	5.8 to 8
Quercus petraea (Matt.) Liebl.	3.1 to 7.7
Quercus pubescens Willd.	4.1 to 4.5
Quercus robur L.	3.1 to 6.2
Quercus rubra L.	3.1 to 8.2
Quercus semecarpifolia Sm.	4 to 7.5
Quercus serrata Murray	4.9 to 5.7
Quercus stellata Wangenh.	4.5 to 8
Quercus velutina Lam.	3.8 to 8
Ranunculus abortivus L.	4.7 to 5.1
Ranunculus acris L.	4.5 to 6.4
Ranunculus auricomus L.	4.1 to 7.7
Ranunculus bulbosus L.	4.3 to 5.9
Ranunculus flammula L.	4.7 to 6.4
Ranunculus polyanthemos L.	4.8 to 7.3
Ranunculus repens L.	4.7 to 8.6
Rhamnus cathartica L.	4 to 4.5
Rhinanthus minor L. [#]	4.3 to 5.9
Rhynchospora alba (L.) Vahl	3.9 to 5.4
Rhynchospora fusca (L.) W.T.Aiton	4.1 to 5.3
Ribes alpinum L.	5.5 to 8.7
Ribes rubrum L.	3.7 to 6.3
Ribes uva-crispa L.	4.4 to 8.7
Robinia pseudoacacia L.	3.8 to 8.2
Rorippa islandica (Oeder) Borbás	6.2 to 9.2
Rosa arvensis Huds.	4.3 to 8.7
Rosa canina L.	3.3 to 8
Rosa carolina L.	3.8 to 4.5
Rosa multiflora Thunb.	6.1 to 6.4
Rubus allegheniensis Porter[#]	4.4 to 5.6
Rubus caesius L.	4.3 to 8.7
Rubus fruticosus L.	2.4 to 8
Rubus idaeus L.	2.4 to 8
Rubus occidentalis L.	4.7 to 5.1
Rubus saxatilis L.	4.2 to 6.2
Rumex acetosa L.	2.9 to 7.2
Rumex acetosella L.	2.9 to 6.3
Rumex obtusifolius L.	5.1 to 6.6
Rumex sanguineus L.	4.2 to 4.4
Ruscus aculeatus L.	4.8 to 5.1
Salicornia europaea L.	3.4 to 9.4
Salix aurita L.	4.1 to 5.3
Salix caprea L.	3.8 to 7.9
Salix caroliniana Michx. [#]	3.1 to 6.4
Salix myrsinites L. [#]	6.6 to 7.8
Sambucus nigra L.	3.1 to 7.6
Sambucus racemosa L.	4 to 6.5
Sanguinaria canadensis L.	4.2 to 5.1

Species	pH range	Species	pH range
Sanguisorba minor Scop.	4.3 to 5.9	*Stellaria graminea L.*	3.1 to 7.7
Sanicula elata Buch.-Ham. ex D. Don	3.7 to 7.2	*Stellaria longifolia (L.) Vill.*	4.5 to 8
Sassafras albidum (Nutt.) Nees	3.3 to 7.2	*Stellaria media L.*	3.3 to 6.3
Saxifraga virginiensis Michx.	4.7 to 5.1	*Stellaria nemorum Ehrh. ex Retz.*	4.7 to 6.4
Schoenoplectus tabernaemontani (C.C.Gmel.) Palla	6.2 to 8.6	*Stellaria uliginosa Murray*	4.7 to 5.8
Scorzonera humilis L.	3.1 to 5.6	*Succisa pratensis Moench*[#]	2.9 to 6.4
Scrophularia nodosa L. [#]	3.1 to 7.2	*Symphyotrichum lateriflorum (L.) Á.Löve & D.Löve*	3.9 to 4.4
Scutellaria galericulata L.	5.5 to 8.9	*Symphyotrichum pilosum (Willd.) G.L.Nesom*	3.9 to 4.4
Sedum maximum (L.) Suter	4.1 to 4.5	*Tanacetum vulgare L.*	7.5 to 7.9
Sedum telephium L.	3.7 to 6.3	*Taraxacum officinale Webb*	3.9 to 8.9
Senecio leucanthemifolius subsp. vernalis (Waldst. & Kit.) Greuter	6.2 to 8.9	*Taraxacum vulgare (Lam.) Schrank*	5.1 to 5.5
Senecio ovatus Willd.	3.7 to 6.3	*Teucrium chamaedrys L.*	4.1 to 4.5
Serratula tinctoria L.	4 to 6.5	*Teucrium scorodonia L.*	3.1 to 6.3
Setaria faberi R.A.W.Herrm.	6.1 to 6.6	*Thalictrum dioicum L.*	4.7 to 5.1
Silene acaulis (L.) Clairv.	4.5 to 5.3	*Tiarella cordifolia L.*	4.2 to 5.1
Silene dioica (L.) Greuter & Burdet	6.7 to 8.3	*Tilia americana L.*	4.1 to 8
Silene nutans L.	3.8 to 8	*Tilia cordata Mill.*	4.8 to 5.1
Silene rupestris L.	4.2 to 5.2	*Tilia platyphyllos Scop.*	5.5 to 8.7
Silene viscaria (L.) Jess.	4 to 6.5	*Torilis japonica (Houtt.) DC.*	3.3 to 6.6
Smilax glauca Walter	3.8 to 6.1	*Toxicodendron radicans (L.) Kuntze*	3.8 to 4.5
Smilax rotundifolia L.	3.8 to 4.5	*Triadenum japonicum (Blume) Makino*	4.6 to 5.3
Solanum dulcamara L.	4.7 to 5.1	*Trichophorum alpinum (L.) Pers.*	4.3 to 7.2
Solanum panduriforme E. Mey. [#]	3.9 to 4.4	*Trichophorum cespitosum (L.) Hartm.*	3.1 to 7.2
Solidago caesia L.	3.8 to 5.1	*Trientalis europaea L.*	2.4 to 5.8
Solidago flexicaulis L.	4.7 to 5.1	*Trifolium arvense L.*	4.2 to 5.2
Solidago rugosa Mill.	4.7 to 5.1	*Trifolium fragiferum L.*	6.2 to 8.6
Solidago virgaurea L.	4 to 6.5	*Trifolium medium L.*	4.5 to 5.1
Sonchus arvensis L.	5.2 to 8.9	*Trifolium pratense L.*	3.1 to 5.9
Sonchus oleraceus (L.) L.	3.4 to 9.4	*Trifolium repens L.*	6.2 to 9.2
Sorbus aria Crantz	4 to 6.5	*Triglochin maritima L.*	3.4 to 9.4
Sorbus aucuparia L.	2.4 to 8	*Trillium erectum L.*	4.7 to 5.1
Sorbus torminalis (L.) Crantz	4 to 4.4	*Trillium grandiflorum (Michx.) Salisb.*	4.2 to 4.5
Spergula morisonii Boreau	4.2 to 5.2	*Tripolium pannonicum (Jacq.) Dobrocz.*	3.4 to 9.4
Spergularia marina (L.) Besser	3.4 to 9.4	*Triticum aestivum L.*	6.5 to 8.9
Stachys officinalis (L.) Trevis.	4.3 to 5.9	*Tsuga canadensis (L.) Carrière*	3.5 to 6.1
Stachys sylvatica L.	3.1 to 8.4	*Tussilago farfara L.*	6 to 7.5
Stellaria borealis L.	4.5 to 5.1	*Ulmus alata Michx.*	5.3 to 5.5

Appendix S2.4

Species	pH range
Ulmus glabra Huds.	3.3 to 8
Ulmus minor Mill.	3.3 to 6.3
Ulmus rubra Muhl.	3.8 to 8
Urtica dioica L.	3.1 to 8.4
Uvularia perfoliata L.	3.8 to 4.5
Uvularia sessilifolia L.	4.7 to 5.1
Vaccinium corymbosum L.	3.5 to 4.1
Vaccinium myrtillus L.	2.4 to 8.5
Vaccinium stenophyllum Steud.	3.4 to 5.6
Vaccinium vitis-idaea L.	3.1 to 5.6
Valeriana jatamansi[#]	3.7 to 6.3
Valeriana repens L.	3.3 to 6.3
Valerianella locusta (L.) Betcke	7.2 to 8
Verbascum thapsus L.	5.2 to 8.4
Vernonia altissima Nutt.	3.9 to 4.4
Veronica chamaedrys L.	3.7 to 8.9
Veronica hederifolia L.	3.1 to 8
Veronica montana L.	3.1 to 8.4
Veronica officinalis L.	3.1 to 7.2
Viburnum acerifolium Gueldenst. ex Ledeb. [#]	3.8 to 5.1
Viburnum lantana L. [#]	5.5 to 8.7
Viburnum opulus L.	4.1 to 8.7
Vicia cracca L.	3.1 to 7.2
Vicia sepium L.	3.3 to 8.7
Vinca minor L.	3.1 to 6.3
Vincetoxicum hirundinaria Medik.	4.1 to 8.4
Viola blanda Salisb. [#]	3.1 to 5.9
Viola calcarata Vill. [#]	4.7 to 5.1
Viola canadensis L.	4.7 to 5.1
Viola collina Besser	3.3 to 6.3
Viola mirabilis L.	3.3 to 6.3
Viola odorata L.	3.3 to 8
Viola palmata L.	3.8 to 4.5
Viola palustris L.	4.7 to 6.4
Viola reichenbachiana Jord. ex Boreau	3.3 to 7.7
Viola riviniana Rchb.	3.3 to 8.7
Viola rotundifolia Hook. [#]	4.7 to 5.1
Viola tricolor L.	4.2 to 5.2
Vitis sp.	3.8 to 4.5
Xanthium strumarium	3.9 to 4.4

(i) Temperate grassland, savanna, and shrubland

Species	pH range
Acer negundo L.	4.9 to 6.3
Acer saccharinum L.	4.9 to 6.3
Achillea millefolium L.	3.3 to 8.7
Aesculus glabra Willd.	4.9 to 5.1
Agoseris glauca (Pursh) Raf.	4.1 to 6.4
Agriophyllum squarrosum (L.) Moq.	4.4 to 7.6
Agropyron sp.	4.1 to 6.4
Agrostis canina L.	3.3 to 6.2
Agrostis capillaris L.	3.3 to 9.1
Agrostis mertensii Trin.	4.4 to 5.8
Agrostis stolonifera L.	4.4 to 8.1
Agrostis vinealis Schreb.	4.3 to 6.1
Aira praecox L.	4.3 to 6.1
Alchemilla glaucescens Wallr.	4.5 to 8.7
Alchemilla vulgaris L.	5 to 5.1
Allium barsczewskii Lipsky	5 to 7
Allium mongolicum Regel	7.3 to 7.6
Alopecurus pratensis L.	5 to 7
Alyssum alyssoides (L.) L.	4.5 to 9.1
Andromeda polifolia L.	4.4 to 5.8
Andropogon gerardii Vitman	7.6 to 7.8
Anemone nemorosa L.	3.3 to 5.7
Anemone pratensis L.	4.5 to 9.1
Antennaria dioica (L.) Gaertn.	4.4 to 5.8
Anthericum liliago L.	4.5 to 9.1
Anthoxanthum odoratum L.	3.3 to 8.7
Anthriscus sylvestris (L.) Hoffm.	5.2 to 8.7
Anthyllis montana L.	6.9 to 7
Anthyllis vulneraria L.	4.5 to 9.1
Anthyllis vulneraria subsp. alpestris (Hegetschw.) Asch. & Graebn.	5 to 5.1
Arctostaphylos alpina (L.) Spreng. [#]	4.4 to 5.8
Arenaria serpyllifolia L.	4.5 to 9.1

Species	pH range
Aristida adscensionis L.	7.3 to 7.6
Arnica montana L.	5 to 5.1
Arrhenatherum elatius (L.) P.Beauv. ex J.Presl & C.Presl.	3.3 to 9.1
Artemisia campestris L.	3.2 to 9.1
Artemisia halodendron Turcz. ex Besser	4.4 to 8.1
Artemisia sieversiana Ehrh.	4.1 to 7.6
Asperula tinctoria L.	5.6 to 8.7
Astragalus alpinus L.	4.4 to 5.8
Astragalus andaulgensis B.Fedtsch.	5 to 7
Astragalus norvegicus Grauer	4.4 to 5.8
Bartsia alpina L.	4.4 to 5.8
Bassia dasyphylla (Fisch. & C.A.Mey.) Kuntze	7 to 7.5
Betula nana L.	4.4 to 5.8
Betula nigra L.	5.4 to 6.3
Botrychium dusenii Alston	4.4 to 5.8
Bouteloua curtipendula (Michx.) Torr.	7.6 to 7.8
Briza media L.	3.3 to 8.7
Bromus erectus Huds.	6 to 6.7
Bromus hordeaceus L.	4.3 to 6.1
Bromus inermis Leyss.	5 to 7
Bupleurum baldense Turra	6 to 6.7
Bupleurum falcatum L.	5 to 7
Calamagrostis epigeios (L.) Roth	2.6 to 7.9
Calluna vulgaris (L.) Hull	3.3 to 7.2
Caltha palustris L.	4.4 to 6.2
Campanula barbata L.	5 to 5.1
Campanula glomerata L.	5 to 7
Campanula persicifolia L.	4.5 to 8.7
Campanula rotundifolia L.	3.3 to 8.7
Caragana microphylla Lam.	4.1 to 7.6
Carex acuta L.	4.6 to 6.2
Carex arenaria L.	4.5 to 9.1
Carex atrata L.	4.4 to 5.8
Carex atrofusca Schkuhr	4.4 to 5.8
Carex bigelowii Torr. ex Schwein.	4.4 to 5.8
Carex canescens L.	4.6 to 6.2
Carex capillaris L.	4.4 to 5.8
Carex caryophyllea Latourr.	3.3 to 8.7
Carex dioica L.	4.4 to 5.8
Carex flacca Schreb.	3.3 to 5.7
Carex glacialis Mack.	4.4 to 5.8
Carex heterostachya Bunge	5 to 7
Carex nigra (L.) Reichard	4.6 to 6.4
Carex panicea L.	4.6 to 6.2
Carex pseudocyperus L.	4.6 to 6.2
Carex riparia Curtis	4.6 to 6.2
Carex rostrata Stokes	4.6 to 6.2
Carex rupestris All.	4.4 to 5.8
Carex sempervirens Vill.	5 to 5.1
Carex stricta Lam.	4.1 to 8.1
Carex turkestanica Regel	5 to 7
Carex vaginata Tausch	4.4 to 5.8
Carex viridula subsp. oedocarpa (Andersson) B.Schmid	5.1 to 5.7
Carya cordiformis (Wangenh.) K.Koch	4.9 to 6.3
Carya laciniosa (F.Michx.) G.Don	4.9 to 6.3
Carya texana Buckley	7.6 to 7.8
Ceanothus americanus L.	4.4 to 7.8
Celtis occidentalis L.	4.9 to 6.3
Centaurea jacea L.	5.2 to 8.7
Centaurea nigra L.	3.3 to 5.7
Centaurea ovina Pall. ex Willd.	5 to 7
Centaurea scabiosa L.	5.6 to 8.7
Centaurium erythraea Rafn	4.3 to 5.4
Cerastium alpinum L.	4.4 to 5.8
Cerastium arvense L.	5 to 7
Cerastium fontanum Baumg.	3.3 to 8.7
Cerastium semidecandrum L.	4.5 to 9.1
Chamorchis alpina (L.) Rich.	4.4 to 5.8
Chenopodium album L.	4.3 to 6.1
Chenopodium glaucum L.	7.3 to 7.6
Cicer songaricum DC.	5 to 7
Cirsium arvense (L.) Scop.	3.3 to 6.1
Cirsium dissectum (L.) Hill	4.6 to 6.5
Cirsium palustre (L.) Coss. ex Scop.	3.3 to 6.7

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Species	pH range
Cladium mariscoides (Muhl.) Torr.	4.1 to 8.1
Cleistogenes squarrosa (Trin. ex Ledeb.) Keng	7.3 to 7.6
Conopodium majus (Gouan) Loret	3.3 to 5.7
Convolvulus arvensis L.	5 to 7
Convolvulus lineatus L.	5 to 7
Corispermum macrocarpum Bunge ex Maxim.	7 to 7.6
Cornus drummondii C.A.Mey.	7.5 to 8.1
Cornus racemosa Lam.	4.4 to 8.1
Corynephorus canescens (L.) P.Beauv.	4.5 to 9.1
Crepis capillaris (L.) Wallr.	5.4 to 6.1
Crepis paludosa (L.) Moench	4.4 to 5.8
Crucianella angustifolia L.	6.2 to 6.7
Cunila origanoides (L.) Britton	4.1 to 7.8
Cynanchum thesioides (Freyn) K.Schum.	7 to 7.6
Cynosurus cristatus L.	4.9 to 7.1
Cytisus scoparius (L.) Link	5 to 6.6
Dactylis glomerata L.	3.3 to 8.7
Dalea purpurea Vent.	7.6 to 7.8
Danthonia spicata (L.) Roem. & Schult.	7.6 to 7.8
Delphinium confusum Popov	5 to 7
Deschampsia cespitosa (L.) P.Beauv.	3.3 to 8.1
Deschampsia flexuosa (L.) Trin.	3.3 to 7.2
Dianthus longicaulis L.	4.5 to 9.1
Dianthus superbus L.	5 to 7
Diapensia lapponica L.	4.4 to 5.8
Digitalis parviflora Jacq.	5 to 5.2
Digitaria ciliaris (Retz.) Koeler	4.4 to 7.6
Doellingeria umbellata (Mill.) Nees	4.4 to 8.1
Drosera rotundifolia L.	5.1 to 5.3
Dryas octopetala L.	4.4 to 5.8
Echinacea pallida (Nutt.) Nutt.	7.6 to 7.8
Eleocharis palustris (L.) Roem. & Schult.	4.6 to 6.2
Eleocharis palustris var. vigens	4.1 to 4.9
Elytrigia repens Desv.	5 to 7
Empetrum nigrum L.	4.4 to 5.8
Epilobium angustifolium L.	3.3 to 8.1
Equisetum fluviatile L.	4.6 to 6.2
Equisetum variegatum Schleich. ex F. Weber & D. Mohr	4.4 to 6.4
Eragrostis pilosa (L.) P.Beauv.	7.3 to 7.6
Erica cinerea L.	4.3 to 6.1
Erica tetralix L.	4.1 to 4.3
Erigeron uniflorus L.	4.4 to 5.8
Eryngium campestre L.	6 to 6.6
Euphorbia corollata L.	7.6 to 7.8
Euphorbia esula L.	7 to 7.6
Euphorbia humifusa Willd.	7.3 to 7.6
Euphrasia frigida Pugsley	4.4 to 5.8
Euphrasia karataviensis Govor.	5 to 7
Euphrasia officinalis L. #	4.3 to 5.4
Euphrasia stricta D.Wolff ex J.F.Lehm.	6.5 to 7.7
Festuca beckeri (Hack.) Trautv.	4.5 to 9.1
Festuca gautieri (Hack.) K.Richt.	7.3 to 7.4
Festuca nigrescens Lam.	5.4 to 6
Festuca ovina L.	3.3 to 8.7
Festuca rubra L.	3.3 to 9.1
Festuca trachyphylla Hack. #	4.5 to 9.1
Festuca valesiaca Schleich. ex Gaudin	5 to 7
Festuca vivipara (L.) Sm.	4.4 to 5.8
Filago pyramidata L.	6 to 6.7
Filipendula vulgaris Moench	4.5 to 8.7
Fragaria moschata Duchesne#	5.6 to 8.7
Fragaria vesca L.	4.5 to 8.7
Fraxinus americana L.	7.6 to 7.8
Fraxinus pennsylvanica Marshall	4.9 to 6.4
Galatella chromopappa Novopokr.	5 to 7
Galium aparine L.	4.4 to 7
Galium boreale L.	4.5 to 8.7
Galium estebanii Sennen	5 to 5.2
Galium mollugo L.	5 to 6.7
Galium saxatile L.	3.3 to 6.1
Galium verum L.	4.5 to 9.1
Genista anglica L.	5.1 to 5.3
Genista sagittalis L.	5 to 6.7
Gentiana nivalis L.	4.4 to 5.8

Species	pH range
Gentiana pneumonanthe L.	5 to 5.2
Gentiana purpurea L.	5 to 5.1
Gentianella amarella (L.) Harry Sm.	4.4 to 5.8
Gentianopsis virgata (Raf.) Holub	4.4 to 8.1
Geranium collinum Stephan ex Willd.	5 to 7
Geranium molle L.	4.3 to 6.1
Geranium sylvaticum L.	4.4 to 8.1
Glandora diffusa (Lag.) D.C.Thomas	5 to 6.7
Globularia cordifolia L.	6.9 to 7
Glyceria fluitans (L.) R.Br.	4.6 to 6.2
Helenium autumnale L.	4.4 to 6
Helianthemum croceum (Cav.) Losa & Rivas Goday	4.5 to 8.7
Helianthemum oelandicum$^{\#}$	6.9 to 7.4
Helianthemum oelandicum (Desf.) Pers.	6.2 to 6.7
Helianthus divaricatus L.	7.6 to 7.8
Helianthus giganteus L.	4.4 to 8.1
Helichrysum arenarium (L.) Moench	3.2 to 9.1
Helictotrichon bromoides (Gouan) C.E.Hubb.	6.2 to 6.7
Helictotrichon marginatum (Lowe) Röser	5 to 6.7
Helictotrichon pratense (L.) Pilg.	4.5 to 8.7
Hieracium echioides Lumn.	5 to 7
Hieracium pilosella L.	3.3 to 5.7
Hieracium umbellatum L.	4.5 to 8.7
Hieracium virosum Pall.	5 to 7
Holcus lanatus L.	3.3 to 6.2
Holcus mollis L.	3.3 to 5.7
Hydrocotyle vulgaris L.	5.2 to 5.8
Hypericum elongatum Ledeb.	5 to 7
Hypericum perforatum L.	4.5 to 8.7
Hypericum scabrum L.	5 to 7
Iris halophila var. sogdiana	5 to 7
Ixeris chinensis (Thunb. ex Thunb.) Nakai	7 to 8.1
Ixiolirion tataricum (Pall.) Schult. & Schult.f.	5 to 7
Juglans nigra L.	4.9 to 5.5
Juncus acutiflorus Ehrh. ex Hoffm.	4.6 to 6.2
Juncus bufonius L.	4.3 to 6.1
Juncus bulbosus L.	4.6 to 6.2
Juncus effusus L.	6.5 to 6.9
Juncus filiformis L.	4.6 to 6.2
Juncus trifidus L.	4.4 to 5.8
Juniperus communis L.	4.4 to 5.8
Juniperus virginiana L.	7.6 to 7.8
Knautia maxima (L.) Coult.	4.5 to 8.7
Koeleria glauca (Spreng.) DC.	4.5 to 9.1
Koeleria macrantha (Ledeb.) Schult.	5.4 to 7
Koeleria micrathera (Desv.) Griseb.	5 to 7
Koeleria vallesiana (Honck.) Bertol. ex Schult.	6.2 to 6.7
Lathyrus linifolius (Reichard) Bassler	4.5 to 7.2
Lathyrus pratensis L.	4.5 to 8.7
Leontodon hispidus L.	3.3 to 5.7
Leontodon taraxacoides (Vill.) Willd. ex Mérat	6 to 6.7
Lespedeza capitata Michx.	7.6 to 7.8
Lespedeza davurica (Laxm.) Schindl.	7 to 7.6
Leucanthemum vulgare (Vaill.) Lam.	4.5 to 8.7
Libanotis schrenkiana C.A. Mey. ex Schischk.	5 to 7
Ligularia macrophylla (Ledeb.) DC.	5 to 7
Linaria vulgaris Mill.	7.3 to 7.6
Lithospermum canescens (Michx.) Lehm.	4.4 to 8.1
Lobelia kalmii L.	4.1 to 4.9
Lotus corniculatus L.	3.3 to 8.7
Luzula campestris (L.) DC.	3.3 to 8.7
Luzula multiflora subsp. frigida (Buchenau) V.I.Krecz.	4.4 to 5.8
Luzula spicata (L.) DC.	4.4 to 5.8
Luzula sudetica (Willd.) Schult.	4.4 to 5.8
Lycopus americanus Muhl. ex W.P.C.Barton	4.4 to 8.1
Maianthemum stellatum (L.) Link	4.4 to 8.1
Malva moschata L.	6 to 6.2
Manfreda virginica (L.) Salisb. ex Rose	7.6 to 7.8
Medicago falcata L.	4.5 to 9.1
Medicago lupulina L.	4.3 to 8.7
Medicago ruthenica (L.) Ledeb.	4.1 to 8.1
Molinia caerulea (L.) Moench	3.3 to 8.1

Appendix S2.4

Species	pH range
Muhlenbergia glomerata (Willd.) Trin.	7.5 to 8.1
Muhlenbergia mexicana (L.) Trin.	4.1 to 6
Myosotis scorpioides L.	4.6 to 6.2
Myosotis sylvatica Ehrh. ex Hoffm.	5 to 7
Nardus stricta L.	3.3 to 6.2
Nepeta mariae Regel	5 to 7
Nepeta nuda subsp. nuda	5 to 7
Nummularia quadriflora (Sims) Farw.	7.4 to 7.9
Omalotheca norvegica (Gunnerus) Sch.Bip. & F.W.Schultz	4.4 to 5.8
Origanum vulgare subsp. gracile (K.Koch) Ietsw.	5 to 7
Orobanche coerulescens Stephan ex Willd.	4.4 to 7.5
Orobanche elatior Sutton	5 to 7
Ostrya virginiana (Mill.) K.Koch	4.1 to 4.9
Oxyria digyna (L.) Hill	4.4 to 5.8
Oxytropis aulieatensis Vved.	5 to 7
Parnassia palustris Parnassia palustris L.	4.4 to 7.3
Parthenocissus quinquefolia (L.) Planch.	4.5 to 7.8
Pedicularis lapponica L. [#]	4.1 to 7.5
Pedicularis nodosa Pennell[#]	5.1 to 5.3
Pedicularis oederi Vahl	4.4 to 5.8
Pedicularis sylvatica L. [#]	4.4 to 5.8
Persicaria vivipara (L.) Ronse Decr.	4.4 to 5.8
Petrorhagia alpina (Hablitz) P.W.Ball & Heywood	5 to 7
Phleum alpinum L.	4.4 to 5.8
Phleum phleoides (L.) H.Karst.	4.5 to 9.1
Phleum pratense L.	4.5 to 8.7
Phragmites australis (Cav.) Trin. ex Steud.	4.7 to 5.3
Phyllodoce caerulea (L.) Bab.	4.4 to 5.8
Physostegia virginiana (L.) Benth.	7.6 to 7.8
Pilosella officinarum Vaill. [#]	4.5 to 9.1
Pilosella peleteriana (Mérat) F.W.Schultz & Sch.Bip. [#]	4.5 to 8.7
Pimpinella saxifraga L.	3.3 to 8.7
Pimpinella tragium Vill. [#]	6.2 to 6.7
Pinguicula vulgaris L.	4.4 to 5.8
Plantago lanceolata L.	3.3 to 8.7
Plantago media L.	6.1 to 8.7
Platanus occidentalis L.	4.9 to 6.3
Poa alpina L.	4.4 to 5.8
Poa angustifolia L.	5 to 7
Poa annua L.	4.3 to 6.1
Poa bulbosa L.	5 to 7
Poa compressa L.	6 to 6.2
Poa humilis Ehrh. ex Hoffm.	4.5 to 8.7
Poa pratensis L.	3.3 to 9.1
Poa pratensis subsp. pratensis	4.5 to 8.7
Poa trivialis L.	4.6 to 6.2
Polygala comosa Schkuhr	5 to 7
Polygala serpyllifolia Hosé	5.1 to 5.3
Polygala vulgaris L.	4.5 to 7.2
Populus deltoides W. Bartram ex Marshall	5.4 to 6.3
Potentilla argentea L.	4.5 to 8.7
Potentilla bifurca var. major	5 to 7
Potentilla crantzii (Crantz) Beck ex Fritsch	4.4 to 5.8
Potentilla erecta (L.) Raeusch.	3.3 to 8.1
Potentilla fruticosa L.	4.1 to 6
Potentilla neumanniana Rchb.	5 to 6.7
Potentilla pedata Nestl.	5 to 7
Potentilla verna L. [#]	5.2 to 8.7
Primula veris L.	5 to 8.7
Prunella vulgaris L.	3.3 to 7
Pseudolysimachion spurium (L.) Rauschert	5 to 7
Pteridium aquilinum (L.) Kuhn	3.3 to 5.7
Pycnanthemum virginianum (L.) T.Durand & B.D.Jacks. ex B.L.Rob. & Fernald	4.1 to 8.1
Quercus alba L.	7.6 to 7.8
Quercus bicolor Willd.	4.9 to 5.9
Quercus coccinea Münchh.	4.4 to 7.8
Quercus macrocarpa Michx.	4.9 to 5.5
Quercus palustris Münchh.	4.9 to 6.3
Quercus stellata Wangenh.	4.1 to 4.9
Quercus velutina Lam.	4.1 to 4.9
Ranunculus acris L.	3.3 to 8.7
Ranunculus bulbosus L.	3.3 to 8.7

Species	pH range
Ranunculus flammula L.	4.6 to 6.2
Ranunculus polyanthemos L.	4.5 to 8.7
Rhinanthus minor L. [#]	4.4 to 5.8
Rhus aromatica Aiton	7.6 to 7.8
Rhus glabra L.	7.6 to 7.8
Rhynchospora alba (L.) Vahl	5.1 to 5.5
Rhynchospora fusca (L.) W.T.Aiton	5.4 to 5.6
Rosa canina L.	6.2 to 6.7
Rubus occidentalis L.	4.4 to 8.1
Rudbeckia hirta L.	4.1 to 4.9
Rumex acetosa L.	3.3 to 8.7
Rumex acetosella L.	4.3 to 9.1
Sagina saginoides (L.) H.Karst.	4.4 to 5.8
Salix gordejevii Y.L. Chang & Skvortsov	7 to 7.6
Salix hastata L.	4.4 to 5.8
Salix lanata L.	4.4 to 5.8
Salix phylicifolia L. [#]	4.4 to 5.8
Salix repens L. [#]	4.4 to 5.8
Salix reticulata L.	4.4 to 5.8
Salsola collina Pall.	7 to 7.6
Saposhnikovia divaricata (Turcz.) Schischk.	7 to 7.6
Saussurea alpina (L.) DC.	4.4 to 5.8
Saxifraga aizoides L.	4.4 to 5.8
Scaligeria setacea (Schrenk) Korovin	5 to 7
Schizachyrium scoparium (Michx.) Nash	4.4 to 8.1
Schmaltzia copallinum (L.) Small	7.6 to 7.8
Scleranthus perennis L.	4.5 to 9.1
Scorzonera turkestanica Franch.	5 to 7
Sedum acre L.	4.5 to 9.1
Sedum forsterianum Sm.	5 to 6.7
Selaginella selaginoides (L.) P. Beauv. ex Mart. & Schrank	4.4 to 5.8
Senecio jacobaea L.	4.3 to 6.1
Seseli libanotis (L.) Koch	6 to 6.7
Seseli mucronatum (Schrenk) Pimenov & Sdobnina	5 to 7
Sesleria albicans Kit.	7.3 to 7.4
Setaria viridis (L.) P.Beauv.	7 to 7.6
Silene himalayensis (L.) Jacq.	4.4 to 5.8
Silene legionensis Lag.	6.2 to 6.7
Silene viscaria (L.) Jess.	4.5 to 8.7
Silphium integrifolium Michx.	4.1 to 8.1
Silphium perfoliatum L.	7.1 to 7.7
Smilax bona-nox L.	4.4 to 7.8
Solidago nemoralis Aiton	7.6 to 7.8
Solidago ohioensis Riddell	4.4 to 8.1
Solidago speciosa A.Gray	7.6 to 7.8
Solidago virgaurea L.	4.4 to 7
Sorghastrum nutans (L.) Nash	7.6 to 7.8
Stachys betoniciflora Rupr.	5 to 7
Stellaria borealis L.	4.5 to 8.7
Stellaria longifolia (L.) Vill.	4.3 to 6.1
Succisa pratensis Moench[#]	5.6 to 6
Symphyotrichum firmum (Nees) G.L.Nesom	7.1 to 7.7
Symphyotrichum oblongifolium (Nutt.) G.L.Nesom	7.6 to 7.8
Symphyotrichum oolentangiense (Riddell) G.L.Nesom	7.5 to 8.1
Symphyotrichum patens (Aiton) G.L.Nesom	7.6 to 7.8
Taraxacum montanum (C.A.Mey.) DC.	5 to 7
Taraxacum officinale Webb	4.3 to 6.1
Teucrium chamaedrys L.	6.2 to 6.7
Teucrium pyrenaicum L.	6.2 to 6.7
Thalictrum alpinum L.	4.4 to 5.8
Thalictrum dasycarpum Fisch., C.A.Mey. & Avé-Lall.	4.1 to 6
Thalictrum minus L.	5 to 7.6
Thymus mastigophorus Lacaita	6.2 to 6.7
Thymus nervosus J.Gay ex Coste	7.3 to 7.4
Thymus pulegioides L.	5 to 6.7
Thymus serpyllum L.	4.5 to 9.1
Tiedemannia rigida (L.) J.M. Coult. & Rose	4.4 to 8.1
Tofieldia pusilla (Michx.) Pers.	4.4 to 5.8
Tragopogon sp.	5 to 7
Trichophorum cespitosum (L.) Hartm.	4 to 4.2
Trifolium alpinum L.	5 to 5.1
Trifolium dubium Sibth.	4.3 to 6.1
Trifolium medium L.	4.5 to 8.7

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Species	pH range
Trifolium pratense L.	4.5 to 8.7
Trifolium repens L.	4.3 to 8.7
Trifolium striatum L.	5 to 6.7
Tripleurospermum maritimum subsp. inodorum (L.)	4.3 to 6.1
Trisetum spicatum (L.) K.Richt.	4.4 to 5.8
Turritis glabra L.	5 to 7
Typha angustifolia L.	4.1 to 6
Ulmus alata Michx.	7.6 to 7.8
Ulmus americana L.	4.9 to 6.3
Vaccinium myrtillus L.	4.4 to 5.8
Vaccinium uliginosum L.	4.4 to 5.8
Vaccinium vitis-idaea L.	4.4 to 5.8
Veronica alpina L.	4.4 to 5.8
Veronica arvensis L.	4.5 to 8.7
Veronica chamaedrys L.	4.5 to 8.7
Veronica officinalis L.	4.5 to 7.2
Vicia cracca L.	4.5 to 8.7
Vicia sativa L.	5.4 to 6.1
Vicia tenuifolia Roth	5 to 7
Viola biflora L.	4.4 to 5.8
Viola blanda Salisb.	4.4 to 8.1
Viola blandiformis Nakai#	5 to 5.1
Viola canina L. #	6.3 to 8.1
Viola riviniana Rchb.	4.1 to 5.7
Ziziphora clinopodioides Lam.	5 to 7

(j) Temperate coniferous forest

Species	pH range
Abies alba Mill.	3.3 to 7.8
Abies cephalonica Loudon	5.1 to 8.3
Acaena novae-zelandiae Kirk#	4.6 to 4.8
Acer hyrcanum Fisch. & C.A.Mey.	7.2 to 7.4
Achillea millefolium L.	4.6 to 6.5
Aciphylla simplicifolia (F.Muell.) Benth.	4.6 to 4.8
Actaea spicata L.	3.3 to 7.8
Adenostyles alliariae (Gouan) A.Kern.	3.6 to 7.8
Adenostyles alpina (L.) Bluff & Fingerh.	3.3 to 7.8
Agrostis capillaris L.	3.3 to 7.8
Agrostis stolonifera L.	3.5 to 6.7
Ajuga reptans L.	3.3 to 7.8
Andromeda polifolia L.	3.3 to 5.3
Anemone blanda Schott & Kotschy	5.1 to 7.4
Anemone nemorosa L.	3.5 to 6.7
Anthoxanthum odoratum L.	4.6 to 6.5
Aremonia agrimonoides (L.) DC.	5.1 to 7.4
Arnica cordifolia Hook.	6.4 to 8.2
Asarum europaeum L.	3.3 to 7.8
Asperula gunnii Hook.f.	4.6 to 4.8
Asplenium ramosum L.	3.3 to 7.8
Aster bellidiastrum (L.) Scop.	3.3 to 7.8
Athyrium filix-femina (L.) Roth	3.3 to 7.8
Balsamorhiza sagittata (Pursh) Nutt.	7 to 8.2
Betula pubescens Ehrh.	3.3 to 5.3
Blechnum spicant (L.) Sm.	3.3 to 7.8
Brachypodium pinnatum (L.) P.Beauv.	7.4 to 8.1
Brachypodium sylvaticum (Huds.) P.Beauv.	6.9 to 7.4
Buphthalmum salicifolium L.	3.3 to 7.8
Calamagrostis arundinacea (L.) Roth	3.5 to 6.1
Calamagrostis epigeios (L.) Roth	3.3 to 7.8
Calamagrostis quadriseta (Labill.) Spreng.	4.6 to 4.8
Calamagrostis rubescens Buckley	6.4 to 8.2
Calamagrostis villosa (Chaix) J.F.Gmel.	3.1 to 6.7
Calluna vulgaris (L.) Hull	3.3 to 5.3
Caltha palustris L.	3.1 to 6.7
Campanula glomerata subsp. glomerata	3.3 to 7.8
Cardamine astoniae I.Thomps.	4.6 to 4.8
Cardamine pratensis L.	4.7 to 6.7
Cardamine trifolia L.	3.5 to 6.1
Carduus defloratus L.	3.3 to 7.8
Carex appressa R.Br.	4.6 to 4.8
Carex brachystachys Schrank	3.3 to 7.8
Carex brizoides L.	3.1 to 6.7
Carex davalliana Sm.	3.3 to 6.7
Carex digitata L.	3.3 to 7.8
Carex echinata Murray	3.1 to 6.7

Species	pH range
Carex flava L.	4.7 to 6.7
Carex humilis Leyss.	3.3 to 7.8
Carex leporina L.	3.3 to 7.5
Carex montana L.	3.3 to 7.8
Carex nigra (L.) Reichard	3.1 to 6.7
Carex ornithopoda subsp. ornithopoda	3.3 to 7.8
Carex pallescens L.	3.3 to 7.8
Carex pauciflora Lightf.	3.1 to 6.7
Carex pendula Huds.	3.3 to 7.8
Carex pilulifera L.	3.3 to 7.8
Carex remota L.	3.3 to 7.8
Carex rostrata Stokes	3.3 to 6.7
Cassinia uncata A.Cunn. ex DC.	4.6 to 4.8
Cephalanthera longifolia (L.) Fritsch	3.3 to 7.8
Chaerophyllum eriopodum (DC.) K.F.Chung[#]	4.6 to 6.5
Chaerophyllum hirsutum L.	3.5 to 6.7
Cirsium erisithales (Jacq.) Scop.	3.3 to 7.8
Cirsium palustre (L.) Coss. ex Scop.	3.3 to 7.8
Clematis vitalba L.	3.3 to 7.8
Convallaria majalis L.	3.3 to 7.8
Cornus suecica L.	3.3 to 5.3
Corydalis solida (L.) Clairv.	6.9 to 7.4
Craspedia aurantia J.Everett & Joy Thomps.	4.6 to 4.8
Crepis fraasii Sch.Bip.	5.1 to 6.3
Crepis paludosa (L.) Moench	3.3 to 6.7
Cruciata glabra (L.) Ehrend.	3.5 to 6.1
Dactylorhiza maculata (L.) Soó	3.5 to 6.7
Daphne mezereum L.	3.3 to 7.8
Deschampsia cespitosa (L.) P.Beauv.	3.3 to 7.8
Deschampsia flexuosa (L.) Trin.	3.3 to 5.3
Digitalis grandiflora Mill.	3.3 to 7.8
Doronicum orientale Hoffm.	5.1 to 7.4
Dorycnium pentaphyllum Scop.	7.4 to 8.1
Dryopteris affinis Fraser-Jenk. [#]	3.3 to 7.8
Dryopteris expansa (C. Presl) Fraser-Jenk. & Jermy	3.1 to 6.1
Dryopteris filix-mas (L.) Schott	3.3 to 7.8
Echium plantagineum L.	6.1 to 6.5
Elymus spicatus (Pursh) Gould	7 to 8.2
Empetrum nigrum L.	3.3 to 5.3
Empetrum nigrum subsp. hermaphroditum (Hagerup) Böcher	3.7 to 3.8
Epilobium montanum L.	3.3 to 7.8
Epipactis atrorubens (Hoffm.) Besser	3.3 to 7.8
Epipactis helleborine (L.) Crantz	3.3 to 7.8
Equisetum palustre L.	3.3 to 6.7
Equisetum sylvaticum L.	3.5 to 6.7
Eriophorum vaginatum L.	3.1 to 4.5
Eucalyptus sp.	4.6 to 4.8
Eupatorium cannabinum L.	3.3 to 7.8
Euphorbia amygdaloides L.	3.3 to 7.8
Euphorbia dulcis L.	3.3 to 7.8
Euphrasia collina R.Br.	4.6 to 4.8
Euphrasia rostkoviana Hayne	4.7 to 6.7
Fagus sylvatica L.	3.3 to 7.8
Festuca heterophylla Lam.	3.5 to 6.7
Filipendula ulmaria (L.) Maxim.	3.5 to 6.7
Fragaria vesca L.	3.5 to 6.1
Fraxinus ornus L.	7.2 to 7.4
Galium album subsp. album	3.3 to 7.8
Galium lucidum All.	3.3 to 7.8
Galium palustre L.	4.7 to 6.7
Galium rotundifolium L.	3.3 to 7.8
Galium sylvaticum L.	3.3 to 7.8
Gentiana asclepiadea L.	3.3 to 7.8
Geranium potentilloides L'Hér. ex DC.	4.6 to 4.8
Geum rivale L.	4.7 to 6.7
Grevillea australis R.Br.	4.6 to 4.8
Gymnocarpium dryopteris (L.) Newman	3.3 to 7.8
Gymnocarpium robertianum (Hoffm.) Newman	3.3 to 7.8
Hedera helix L.	3.3 to 7.8
Helichrysum microcephalum A.Cunn. ex DC.	4.6 to 4.8
Helictotrichon convolutum (J.Presl) Henrard	7.2 to 8.3
Heracleum austriacum L. [#]	3.3 to 7.8
Hieracium murorum L.	3.5 to 6.1
Hovea montana (Hook.f.) J.H.Ross	4.6 to 4.8

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Species	pH range
Huperzia selago (L.) Bernh. ex Schrank & Mart.	3.3 to 7.8
Hypericum hirsutum L.	3.3 to 7.8
Hypericum maculatum subsp. immaculatum (Murb.) A.Fröhl.	3.3 to 7.8
Hypochoeris radicata L.	5.2 to 6.5
Juncus effusus L.	3.3 to 7.8
Juncus filiformis L.	3.1 to 4.3
Juniperus oxycedrus L.	5.1 to 8.3
Knautia arvensis#	3.3 to 7.8
Larix decidua Mill.	3.3 to 7.8
Laserpitium latifolium L. #	3.3 to 7.8
Lilium chalcedonicum L.	6.9 to 7.4
Lilium martagon L.	3.3 to 7.8
Linnaea borealis L.	3.3 to 4.5
Lonicera hetrusca Host#	3.3 to 7.8
Lonicera periclymenum Lour. #	7.2 to 7.4
Luzula luzulina (Vill.) Racib.	3.1 to 7.8
Luzula luzuloides (Lam.) Dandy & Wilmott	3.5 to 6.1
Luzula nodulosa E.Mey.	7.2 to 7.4
Luzula novae-cambriae Gand.	4.6 to 4.8
Luzula pilosa (L.) Willd.	3.1 to 7.5
Luzula sylvatica subsp. sylvatica	3.3 to 7.8
Lycopodium annotinum L.	3.3 to 7.8
Maianthemum bifolium (L.) F.W.Schmidt	3.1 to 6.7
Melampyrum pratense L.	3.3 to 5.3
Melica nutans L.	3.3 to 7.8
Melittis melissophyllum subsp. carpatica (Klokov) P.W.Ball	3.3 to 7.8
Mentha longifolia (L.) L.	3.3 to 7.8
Mercurialis perennis L.	3.3 to 7.8
Mniarum biflorum J.R. Forst. & G. Forst.	4.6 to 4.8
Moehringia muscosa L.	3.3 to 7.8
Molinia caerulea (L.) Moench	3.3 to 7.8
Mycelis muralis (L.) Dumort.	3.3 to 7.8
Myosotis densiflora C. Koch	5.1 to 7.4
Nardus stricta L.	3.3 to 6.7
Neillia monogyna var. malvacea	6.4 to 8.2
Neottia nidus-avis (L.) Rich.	3.3 to 7.8
Olearia phlogopappa (Labill.) DC.	4.6 to 4.8
Oreopteris limbosperma Holub	3.3 to 7.8
Origanum vulgare L.	3.3 to 7.8
Ostrya carpinifolia Scop.	7.2 to 7.4
Oxalis acetosella L.	3.5 to 6.7
Paris quadrifolia L.	3.3 to 7.8
Parnassia palustris Parnassia palustris L.	3.5 to 6.7
Persicaria vivipara (L.) Ronse Decr.	4.1 to 5.6
Phegopteris connectilis (Michx.) Watt	3.3 to 7.8
Phillyrea latifolia L.	7.7 to 8.3
Picea abies (L.) H.Karst.	3.1 to 7.8
Pimelea alpina F. Muell. ex Meisn.	4.6 to 4.8
Pimpinella major (L.) Huds.	3.3 to 7.8
Pinguicula vulgaris L.	4.7 to 6.7
Pinus nigra subsp. pallasiana (Lamb.) Holmboe	4.5 to 8.3
Pinus sylvestris L.	3.3 to 5.3
Platanus orientalis L.	7.7 to 8.3
Poa alpina L.	3.5 to 6.1
Poa fawcettiae Vickery	4.6 to 4.8
Poa helmsii Vickery	4.6 to 4.8
Poa hiemata Vickery	4.6 to 4.8
Polygala chamaebuxus L.	3.3 to 7.8
Polygala vulgaris L.	4.7 to 6.7
Polygonatum multiflorum (L.) All.	3.3 to 7.8
Polygonatum verticillatum (L.) All.	3.3 to 7.8
Polystichum aculeatum (L.) Schott	3.3 to 7.8
Poranthera microphylla Brongn.	4.6 to 4.8
Potentilla erecta (L.) Raeusch.	3.1 to 6.7
Potentilla micrantha Ram. ex DC.	6.9 to 7.4
Prasophyllum alpestre D.L.Jones	4.6 to 4.8
Pseudotsuga menziesii (Mirb.) Franco	6.4 to 7
Pteridium aquilinum (L.) Kuhn	3.3 to 7.8
Pulmonaria officinalis L. #	3.3 to 7.8
Quercus coccifera L.	7.7 to 8.3
Ranunculus acris L.	4.7 to 6.7
Ranunculus graniticola Melville##	4.6 to 4.8
Ranunculus serpens subsp. nemorosus (DC.) G.López	3.3 to 7.8

Species	pH range
Rhododendron hirsutum L. [#]	3.3 to 7.8
Ribes uva-crispa L.	6.9 to 7.4
Rosa pendulina L. [#]	3.3 to 7.8
Rubus chamaemorus L.	3.3 to 5.3
Rubus idaeus L.	3.3 to 7.8
Salix aurita L.	3.3 to 5.3
Salvia glutinosa L.	3.3 to 7.8
Scilla bifolia L.	6.9 to 7.4
Scrophularia nodosa L. [#]	3.3 to 7.8
Sesleria albicans Kit.	3.3 to 7.8
Silene italica (L.) Pers.	6.9 to 7.4
Solidago virgaurea L.	3.3 to 7.8
Sorbus aria Crantz	3.3 to 7.8
Sorbus aucuparia L.	3.3 to 7.8
Stachys alopecuros (L.) Benth.	3.3 to 7.8
Stellaria patens[#]	4.6 to 4.8
Taraxacum officinale Webb	3.3 to 7.5
Trichophorum alpinum (L.) Pers.	4.7 to 6.7
Trientalis europaea L.	3.3 to 5.3
Trifolium heldreichianum Hausskn.	7.4 to 8.1
Trifolium pratense L.	3.5 to 6.7
Trifolium repens L.	3.5 to 6.7
Ulmus glabra Huds.	3.3 to 7.8
Vaccinium myrtillus L.	3.1 to 7.8
Vaccinium oxycoccos L.	3.1 to 6.7
Vaccinium uliginosum L.	3.3 to 5.3
Vaccinium vitis-idaea L.	3.1 to 6.7
Valeriana capitata[#]	3.3 to 7.8
Valeriana capitata Pall. ex Link[#]	3.3 to 7.5
Valeriana officinalis[#]	3.3 to 7.8
Veratrum album L.	3.3 to 7.8
Veronica chamaedrys L.	3.3 to 7.5
Veronica officinalis L.	3.3 to 7.8
Vincetoxicum hirundinaria Medik.	3.3 to 7.8
Viola biflora L.	3.5 to 6.7
Viola riviniana Rchb.	5.1 to 6.3
(k) Montane grassland and savanna	
Acronema nervosum H.Wolff	6 to 7
Ajuga integrifolia Buch.-Ham.	6 to 7
Allium hypsistum Stearn	6 to 7
Anaphalis triplinervis (Sims) Sims ex C.B.Clarke	6 to 7
Andropogon munroi C.B.Clarke	6 to 7
Androsace globifera Duby	6 to 7
Anemone rivularis Buch.-Ham. ex DC.	6 to 7
Arabis pterosperma Edgew.	6 to 7
Arisaema flavum (Forssk.) Schott	6 to 7
Artemisia biennis Willd.	6 to 7
Artemisia carvifolia Buch.-Ham. ex Roxb.	6 to 7
Artemisia gmelinii Weber	6 to 7
Aster himalaicus C.B.Clarke	6 to 7
Aster indamellus Griers.	6 to 7
Astragalus rhizanthus Benth.	6 to 7
Axyris hybrida L.	6 to 7
Berberis ceratophylla G.Don	6 to 7
Brachypodium sylvaticum (Huds.) P.Beauv.	6 to 7
Brassica rapa L.	6 to 7
Briza media L.	6 to 7
Bromus himalaicus Stapf	6 to 7
Bupleurum hamiltonii N.P.Balakr.	6 to 7
Calamagrostis lahulensis G.Singh	6 to 7
Caltha palustris L.	6 to 7
Campanula pallida Wall	6 to 7
Cannabis sativa L	6 to 7
Capsella bursa-pastoris (L.) Medik.	6 to 7
Carex orbicularis Boott	6 to 7
Chenopodium album L.	6 to 7
Chenopodium foliosum Asch.	6 to 7
Chesneya cuneata (Benth.) Ali	6 to 7
Cirsium falconeri (Hook.f.) Petr.	6 to 7
Clematis graveolens Lindl.	6 to 7
Convolvulus arvensis L.	6 to 7
Cotoneaster microphyllus var. thymifolius	6 to 7
Crepis elongata Babc.	6 to 7

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Species	pH range
Crucihimalaya himalaica (Edgew.) Al-Shehbaz, O'Kane & R.A.Price	6 to 7
Cuscuta europaea L.	6 to 7
Cynoglossum zeylanicum (Lehm.) Brand	6 to 7
Dactylis glomerata L.	6 to 7
Danthonia cumminsii Hook.f.	6 to 7
Delphinium williamsii Munz	6 to 7
Deschampsia cespitosa (L.) P.Beauv.	6 to 7
Dicranostigma lactucoides Hook.f. & Thomson	6 to 7
Dipsacus inermis[#]	6 to 7
Dysphania ambrosioides (L.) Mosyakin & Clemants	6 to 7
Elephantopus scaber L.	6 to 7
Elsholtzia eriostachya (Benth.) Benth.	6 to 7
Ephedra gerardiana Wall. ex Stapf	6 to 7
Epipactis royleana Lindl.	6 to 7
Equisetum arvense L.	6 to 7
Eragrostis nigra Nees ex Steud.	6 to 7
Erica arborea L.	5.5 to 6
Erigeron uniflorus L.	6 to 7
Eritrichium minimum (Brand) H.Hara	6 to 7
Erodium stephanianum Willd.	6 to 7
Erysimum benthamii Monnet	6 to 7
Euphrasia platyphylla Pennell	6 to 7
Fagopyrum acutatum (Lehm.) Mansf. ex K.Hammer	6 to 7
Fagopyrum esculentum Moench	6 to 7
Galium acutum Edgew.	6 to 7
Galium aparine L.	6 to 7
Gaultheria trichophylla Royle	6 to 7
Gentiana crassuloides Bureau & Franch.	6 to 7
Gentiana pedicellata (D.Don) Wall.	6 to 7
Gentiana robusta King ex Hook.f.	6 to 7
Geranium donianum Sweet	6 to 7
Gerbera nivea (DC.) Sch.Bip.	6 to 7
Gnaphalium affine D.Don	6 to 7
Halenia elliptica D.Don	6 to 7
Hedysarum campylocarpon H.Ohashi	6 to 7
Heracleum nepalense D. Don	6 to 7
Herminium macrophyllum (D.Don) Dandy	6 to 7
Hippolytia gossypina (C.B.Clarke) C.Shih	6 to 7
Hippophae tibetana Schltdl.	6 to 7
Hypericum revolutum Vahl	5.5 to 6
Juncus triglumis L.	6 to 7
Juniperus indica Bertol.	6 to 7
Krascheninnikovia ceratoides (L.) Gueldenst.	6 to 7
Leontopodium jacotianum Beauverd	6 to 7
Lepidium apetalum Willd.	6 to 7
Leymus secalinus (Georgi) Tzvelev	6 to 7
Lilium nepalense D.Don	6 to 7
Lobelia doniana Skottsb. [#]	6 to 7
Lonicera alpigena K.S. Hao ex P.S. Hsu & H.J. Wang	6 to 7
Lotus corniculatus L.	6 to 7
Malaxis muscifera (Lindl.) Kuntze	6 to 7
Malva neglecta Wallr.	6 to 7
Medicago edgeworthii Sirj.	6 to 7
Medicago falcata L.	6 to 7
Medicago lupulina L.	6 to 7
Miscanthus nepalensis (Trin.) Hack.	6 to 7
Morina polyphylla Wall. ex DC. [#]	6 to 7
Nepeta ciliaris Benth.	6 to 7
Origanum vulgare L.	6 to 7
Oxytropis microphylla (Pall.) DC.	6 to 7
Oxytropis williamsii Vassilcz.	6 to 7
Pedicularis lanceolata Michx. [#]	6 to 7
Pennisetum flaccidum Griseb.	6 to 7
Persicaria nepalensis (Meisn.) Miyabe	6 to 7
Phleum alpinum L.	6 to 7
Picris angustifolia subsp. angustifolia DC.	6 to 7
Pinus wallichiana A.B.Jacks.	6 to 7
Plantago holosteum Scop. [#]	6 to 7
Poa annua L.	6 to 7
Polygonatum verticillatum (L.) All.	6 to 7
Polygonum polystachyum var. polystachyum[#]	6 to 7
Polygonum rottboellioides Jaub. & Spach	6 to 7

Species	pH range
Potentilla anserina L.	6 to 7
Potentilla cuneata Wall. ex Lehm.	6 to 7
Potentilla fruticosa L.	6 to 7
Potentilla lineata Trevir.	6 to 7
Potentilla sericea L.	6 to 7
Pterocephalus hookeri (C.B. Clarke) Diels	6 to 7
Rosa sericea Lindl.	6 to 7
Rubus pungens Cambess.	6 to 7
Rumex nepalensis Spreng.	6 to 7
Saccharum rufipilum Steud.	6 to 7
Salvia hians Royle ex Benth.	6 to 7
Salvia nubicola Wall. ex Sweet	6 to 7
Saussurea stracheyana (Kuntze) Lipsch. #	6 to 7
Schefflera abyssinica (Hochst. ex A.Rich.) Harms	5.5 to 6.2
Selinum wallichianum (DC.) Raizada & H.O. Saxena	6 to 7
Sibbaldia cuneata Hornem. ex Kuntze	6 to 7
Silene gonosperma (Rohrb.) Majumdar	6 to 7
Stellaria palustris D. Don	6 to 7
Stellera chamaejasme L.	6 to 7
Swertia ciliata (D. Don ex G. Don) B.L. Burtt	6 to 7
Taraxacum eriopodum (D.Don) DC.	6 to 7
Taraxacum nepalense Soest#	6 to 7
Thalictrum alpinum L.	6 to 7
Themeda triandra Forssk.	6 to 7
Thymus linearis Benth.	6 to 7
Trifolium pratense L.	6 to 7
Triticum aestivum L.	6 to 7
Valeriana tripteris Jones	6 to 7
Verbascum thapsus L.	6 to 7
Viola pilosa Blume	6 to 7
(l) Boreal forest / taiga	
Abies balsamea (L.) Mill.	5.3 to 6.9
Acer platanoides L.	4 to 6.1
Achillea millefolium L.	5.3 to 6.9
Aconitum septentrionale Koelle	4.1 to 6.4

Species	pH range
Actaea spicata L.	4.1 to 6.4
Aegopodium podagraria L.	5.1 to 7.7
Agrostis capillaris L.	3.7 to 5.3
Alnus incana (L.) Moench	4.4 to 7.7
Alnus viridis (Chaix) DC.	5.3 to 6.9
Anaphalis margaritaceae L. #	5.3 to 6.9
Anthoxanthum odoratum L.	3.7 to 5.3
Arctostaphylos uva-ursi (L.) Spreng.	3.2 to 4.8
Aster sp.	5.3 to 6.9
Athyrium filix-femina (L.) Roth	4.4 to 5.8
Aucuparia americana (Marshall) Nieuwl.	5.3 to 6.9
Betula pendula Roth	5.1 to 7.7
Betula pubescens Ehrh.	3.2 to 6.1
Betula pumila L.	5.3 to 6.9
Calamagrostis purpurea (Trin.) Trin.	4.4 to 5.8
Calluna vulgaris (L.) Hull	3.2 to 4.8
Carex digitata L.	4 to 6.1
Chrysanthemum sp.	5.3 to 6.9
Cicerbita alpina (L.) Wallr.	4.4 to 5.8
Clintonia borealis (Sol.) Raf.	5.3 to 6.9
Convallaria majalis L.	5.1 to 7.7
Corylus avellana L.	4 to 6.1
Crepis paludosa (L.) Moench	4.4 to 5.8
Cylactis pubescens (Raf.) W.A. Weber	5.3 to 6.9
Deschampsia flexuosa (L.) Trin.	3.2 to 6.1
Diphasiastrum complanatum (L.) Holub	3.2 to 4.4
Dryopteris expansa (C. Presl) Fraser-Jenk. & Jermy	3.5 to 5.3
Dryopteris filix-mas (L.) Schott	4 to 6.1
Empetrum nigrum L.	6.3 to 6.9
Empetrum nigrum subsp. hermaphroditum (Hagerup) Böcher	3.2 to 4.8
Epilobium angustifolium L.	5.3 to 6.9
Equisetum sp.	5.8 to 6.9
Filipendula ulmaria (L.) Maxim.	4.4 to 5.8
Fragaria vesca L.	4 to 6.9
Galium triflorum Michx.	4.1 to 6.4
Gaultheria hispidula (L.) Muhl. ex Bigelow	5.3 to 6.9
Geranium sylvaticum L.	5.1 to 7.7

Appendix S2.4

Species	pH range
Geum rivale L.	4.4 to 5.8
Goodyera repens (L.) R.Br.	3.2 to 4.4
Gymnocarpium dryopteris (L.) Newman	3.5 to 6.4
Hepatica nobilis Mill.	4 to 6.1
Hieracium murorum L.	4 to 6.1
Iris versicolor L.	5.3 to 6.9
Juniperus communis L.	5.3 to 6.9
Kalmia angustifolia L.	5.3 to 6.9
Larix laricina (Du Roi) K.Koch	5.3 to 6.9
Lathyrus linifolius (Reichard) Bassler	4 to 6.1
Leontodon autumnalis L.	5.3 to 6.9
Linnaea borealis L.	3.2 to 6.9
Luzula pilosa (L.) Willd.	3.5 to 5.1
Lycopodium annotinum L.	3.5 to 5.1
Maianthemum bifolium (L.) F.W.Schmidt	3.5 to 5.4
Maianthemum canadense Desf.	5.3 to 6.9
Melampyrum lineare Lam. #	3.7 to 5.3
Melampyrum pratense L.	4.9 to 5.7
Melica nutans L.	4 to 6.1
Milium effusum L.	4.4 to 5.8
Oreopteris limbosperma Holub	3.7 to 5.3
Orthilia secunda (L.) House	3.5 to 5.1
Oxalis acetosella L.	3.7 to 6.4
Phegopteris connectilis (Michx.) Watt	4.4 to 5.8
Picea abies (L.) H.Karst.	3.2 to 7.7
Picea mariana (Mill.) Britton, Sterns & Poggenb.	5.3 to 6.9
Pinus sylvestris L.	3.2 to 6.1
Plantago major L.	6.8 to 6.9
Populus tremula L.	5.1 to 7.7
Populus tremuloides Michx.	5.3 to 6.9
Pyrola chlorantha Sw.	3.2 to 4.4
Pyrola rotundifolia L.	5.1 to 6.1
Rhododendron groenlandicum (Oeder) Kron & Judd	5.3 to 6.9
Rubus idaeus L.	4.1 to 6.4
Rubus saxatilis L.	5.1 to 6.1
Salix myrsinifolia Salisb.	4.4 to 5.8
Salix repens L. #	4.4 to 5.8
Solidago virgaurea L.	4.1 to 5.4
Sorbus aucuparia L.	3.7 to 7.7
Spiraea alba var. latifolia#	5.3 to 6.9
Trientalis borealis Raf.	5.3 to 6.9
Trientalis europaea L.	3.5 to 5.3
Trifolium repens L.	5.8 to 6.9
Trollius europaeus L.	4.4 to 7.7
Vaccinium myrtillus L.	3.2 to 6.1
Vaccinium stenophyllum Steud.	5.3 to 6.9
Vaccinium vitis-idaea L.	3.2 to 6.9
Veronica officinalis L.	4 to 6.1
Viola riviniana Rchb.	4 to 6.1
(m) Tundra and alpine lands	
Aconitum paradoxum Rchb.	4.5 to 7.9
Aconitum septentrionale Koelle	4.4 to 4.5
Alchemilla alpina L. #	4.4 to 4.5
Anemone richardsonii Hook.	5 to 7.4
Antennaria alpina (L.) Gaertn.	4.4 to 4.5
Antennaria dioica (L.) Gaertn.	4.4 to 4.5
Arctagrostis arundinacea (Trin.) Beal	5 to 7.4
Arctagrostis latifolia (R.Br.) Griseb.	5 to 7.9
Arctophila fulva (Trin.) Andersson	7 to 7.4
Arctous alpinus (L.) Nied.	4.6 to 5.2
Arenaria humifusa Wahlenb.	6.2 to 7.7
Argyrotegium poliochlorum (N.G.Walsh) J.M.Ward & Breitw.	4.4 to 4.5
Artemisia arctica (Besser) Leonova	4.5 to 7.9
Artemisia tilesii Ledeb.	5 to 7.9
Astragalus alpinus L.	4.4 to 7.7
Astragalus umbellatus Bunge	6 to 7.5
Bartsia alpina L.	4.4 to 4.5
Beckwithia glacialis (L.) Á.Löve & D.Löve	4.9 to 5.2
Betula nana L.	4.6 to 5.2
Campanula rotundifolia L.	4.4 to 4.5
Campanula uniflora L.	6.2 to 7.7
Cardamine digitata Richardson	5 to 7.9
Cardamine microphylla Adams	5 to 7.9

Supporting information

Species	pH range
Carex aquatilis Wahlenb.	5.3 to 7
Carex atrofusca Schkuhr	7 to 7.4
Carex bigelowii Torr. ex Schwein.	4.6 to 7.4
Carex capillaris L.	6.2 to 7.7
Carex fuliginosa Schkuhr	6 to 7.9
Carex glacialis Mack.	6.2 to 7.7
Carex lachenalii subsp. lachenalii	5 to 7.9
Carex marina Dewey	6.9 to 7.3
Carex membranacea Hook.	7.3 to 7.4
Carex microchaeta subsp. nesophila (Holm) D.F.Murray	4.5 to 6.9
Carex nardina (Hornem.) Fr.	6.2 to 7.7
Carex podocarpa R.Br.	4.5 to 7.9
Carex rotundata Wahlenb.	7 to 7.3
Carex rupestris All.	4.9 to 7.7
Carex saxatilis L.	7 to 7.4
Carex scirpoidea Michx.	5 to 7.9
Cassiope tetragona (L.) D.Don	4.5 to 7.9
Cerastium alpinum L.	4.4 to 7.7
Cerastium cerastoides (L.) Britton	4.4 to 4.5
Cerastium fontanum Baumg.	4.4 to 4.5
Cirsium helenioides (L.) Hill	4.4 to 4.5
Crepis paludosa (L.) Moench	4.4 to 4.5
Diapensia lapponica L.	4.6 to 7.7
Diapensia lapponica subsp. obovata (F.Schmidt) Hultén	4.5 to 6.9
Disterigma microphyllum (G.Don) Luteyn	4.5 to 7.4
Draba alpina L.	6.9 to 7.3
Draba chamissonis G.Don	4.5 to 7.9
Dryas integrifolia f. canescens (Simmons) Fernald	6 to 7.9
Dryas integrifolia Vahl	5 to 7.9
Dryas octopetala L.	4.6 to 7.7
Dupontia fisheri R.Br.	5.3 to 7.4
Empetrum nigrum subsp. hermaphroditum (Hagerup) Böcher	4.6 to 7.7
Empetrum nigrum subsp. subholarcticum (V.N.Vassil.) Kuvaev	4.5 to 6.9
Epilobium anagallidifolium Lam.	4.4 to 4.5
Epilobium latifolium L.	5 to 7.4
Equisetum boreale Bong.	5 to 7.9
Equisetum variegatum Schleich. ex F. Weber & D. Mohr	5 to 7.4
Erigeron humilis Graham	6 to 7.9
Eriophorum angustifolium Honck.	5.3 to 7.3
Eriophorum angustifolium subsp. triste (T.C.E.Fr.) Hultén	6.9 to 7
Eriophorum russeolum Fr.	6.9 to 7
Eriophorum vaginatum L.	4 to 7.3
Euphrasia frigida Pugsley	4.4 to 4.5
Euphrasia wettsteinii G.L.Gusarova	6.2 to 7.7
Festuca altaica Trin. ex Ledeb.	4.5 to 7.9
Festuca ovina L.	4.9 to 7.7
Festuca vivipara (L.) Sm.	4.9 to 7.7
Fragaria vesca L.	4.4 to 4.5
Gentiana glauca Pall.	4.5 to 6.4
Gentianella propinqua (Richardson) J.M.Gillett	4.5 to 7.9
Geranium sylvaticum L.	4.4 to 4.5
Geum rivale L.	4.4 to 4.5
Hedysarum hedysaroides (L.) Schinz & Thell.	4.5 to 7.9
Hieracium alpinum L.	4.4 to 4.5
Hierochloe alpina (Sw.) Roem. & Schult.	4.9 to 5.2
Hulteniella integrifolia (Richardson) Tzvelev	6 to 7.9
Huperzia selago (L.) Bernh. ex Schrank & Mart.	4.9 to 7.7
Juncus biglumis L.	7 to 7.7
Juncus trifidus L.	4.6 to 7.7
Ledum palustre var. decumbens	4 to 7.3
Leontodon autumnalis L.	4.4 to 4.5
Lloydia serotina (L.) Rchb.	5 to 7.9
Lotus corniculatus L.	4.4 to 4.5
Luzula arcuata (Wahlenb.) Sw.	4.6 to 7.7
Luzula arcuata subsp. unalaschkensis (Buchenau) Hultén	5 to 6.4
Luzula spicata (L.) DC.	6.2 to 7.7
Maianthemum bifolium (L.) F.W.Schmidt	4.4 to 4.5
Melampyrum lineare Lam.[#]	4.4 to 4.5
Melampyrum pratense L.	4.4 to 4.5
Minuartia arctica (Steven ex Ser.) Graebn.	5.5 to 7.9
Minuartia stricta (Sw.) Hiern	6.2 to 7.7

Appendix S2.4

Species	pH range
Myosotis decumbens Host	4.4 to 4.5
Omalotheca norvegica (Gunnerus) Sch.Bip. & F.W.Schultz	4.4 to 4.5
Oxyria digyna (L.) Hill	4.5 to 7.9
Oxytropis lapponica (Wahlenb.) Gay	6.2 to 7.7
Oxytropis nigrescens (Pall.) DC.	7 to 7.5
Papaver macounii Greene#	7.3 to 7.7
Parnassia kotzebuei Cham. ex Spreng. #	5 to 7.9
Parnassia palustris Parnassia palustris L.	4.4 to 7.4
Parrya nudicaulis (L.) Boiss.	5 to 7.9
Pedicularis capitata Adams	4.5 to 7.9
Pedicularis flammea L. #	6.2 to 7.7
Pedicularis hirsuta L. #	4.6 to 7.7
Pedicularis sylvatica L. #	4 to 7.3
Persicaria vivipara (L.) Ronse Decr.	4.4 to 7.9
Petasites frigidus (L.) Fr.	5 to 7.4
Phyllodoce caerulea (L.) Bab.	4.5 to 7.4
Pinguicula vulgaris L.	4.4 to 4.5
Poa arctica R.Br.	4.5 to 7.4
Poa lanata Scribn. & Merr.	5 to 7.9
Poa paucispicula Scribn. & Merr.	5 to 7.9
Polemonium caeruleum var. acutiflorum	5 to 7.9
Polygonum ellipticum Willd. ex Spreng.	5 to 6.4
Potentilla crantzii (Crantz) Beck ex Fritsch	4.4 to 4.5
Potentilla erecta (L.) Raeusch.	4.4 to 4.5
Potentilla fruticosa var. fruticosa	4.5 to 7.4
Potentilla hyparctica Malte	4.5 to 6.9
Puccinellia wrightii (Scribn. & Merr.) Tzvelev	6.5 to 7.9
Pyrola minor L.	4.4 to 4.5
Pyrola rotundifolia L.	4.4 to 4.5
Ranunculus acris L.	4.4 to 4.5
Ranunculus nivalis L.	5 to 7.9
Ranunculus platanifolius L.	4.4 to 4.5
Ranunculus pygmaeus Wahlenb.	5 to 7.9
Rhinanthus minor L. #	4.4 to 4.5
Rhodiola atropurpurea (Turcz.) Trautv. & Mey. in Middendorf	4.5 to 7.4
Rhododendron lapponicum (L.) Wahlenb.	6.2 to 7.7
Rubus chamaemorus L.	4 to 7.3
Rumex acetosa L.	4.4 to 4.5
Rumex aquaticus subsp. arcticus (Trautv.) Hiitonen	5 to 7.9
Sagina procumbens L.	4.4 to 4.5
Sagina saginoides (L.) H.Karst.	4.4 to 4.5
Salix chamissonis Andersson	4.5 to 7.4
Salix polaris Wahlenb.	5 to 7.9
Salix reticulata L.	4.5 to 7.9
Salix reticulata var. reticulata	6.9 to 7.3
Salix richardsonii Hook.	6.9 to 7.4
Salix rotundifolia Trautv.	5.3 to 7.9
Saussurea alpina (L.) DC.	4.4 to 4.5
Saussurea angustifolia (L.) DC.	4.5 to 7.9
Saxifraga aizoides L.	7 to 7.7
Saxifraga hieraciifolia Waldst. & Kit. ex Willd.	5 to 7.4
Saxifraga hirculus L.	5 to 7.9
Saxifraga nelsoniana D.Don	4.5 to 7.9
Saxifraga oppositifolia L.	4.6 to 7.9
Sibbaldia procumbens L.	4.4 to 4.5
Silene acaulis (L.) Clairv.	4.4 to 4.5
Silene himalayensis (L.) Jacq.	4.9 to 7.7
Solidago compacta Turcz.	4.5 to 7.4
Solidago virgaurea L.	4.4 to 4.5
Stellaria pungens Bigelow	4.4 to 4.5
Taraxacum alaskanum Rydb.	5 to 7.9
Thalictrum alpinum L.	4.4 to 7.9
Therorhodion camtschaticum (Pall.) Small	4.5 to 6.9
Tofieldia coccinea Richardson	4.5 to 7.9
Tofieldia pusilla (Michx.) Pers.	4.9 to 7.9
Trientalis europaea L.	4.4 to 4.5
Trisetum spicatum (L.) K.Richt.	4.5 to 7.9
Vaccinium minus Vorosch.	4 to 7.3
Vaccinium uliginosum L.	6.2 to 7.7
Vaccinium vitis-idaea L.	4.9 to 7.7
Valeriana saxatilis L. #	5 to 7.9
Veronica alpina L.	4.4 to 4.5
Veronica fruticans Jacq. #	4.4 to 4.5

Species	pH range
Viola biflora L.	4.4 to 4.5
Viola epipsiloides Á.Löve & D.Löve	5 to 6.9
Viola palustris L.	4.4 to 4.5
Wilhelmsia physodes (Fisch. ex Ser.) McNeill	5 to 7.9

[#] *Taxonomy is unresolved according to The Plant List* (2010).

Appendix S2.5

Appendix S2.5 Sensitivity analysis of the variability within biomes

We performed a sensitivity analysis by investigating the success in deriving PNOF – soil pH log-logistic functions at three spatial resolution levels. First, we allocated studies into ecoregions. Figure S2.5.1 shows an example of the aggregation procedure of studies within ecoregions and of the same biome.

In order to avoid double counting of plant species – pH ranges, we did not include studies that covered two or more ecoregions. Also, we did not include studies where the described vegetation is outside the boundaries of the corresponding biome (Figure 2.1, main text).

After deriving logistic regressions for all ecoregions, we proceeded with the sensitivity analysis of the PNOF – soil pH functions across ecoregions and across studies within the same biome.

An overview of the data available by ecoregion (Table S2.5.1 of this appendix) and per individual studies (Table S2.3.1 of appendix S2.3) are available in this supporting information. The log-logistic results per ecoregion (Table S2.5.2) show that we were able to successfully derive log-logistic regressions for few ecoregions. Likewise, at an even more detailed spatial resolution (i.e. studies), the success in deriving PNOF – pH functions was even lower (Table S2.5.3).

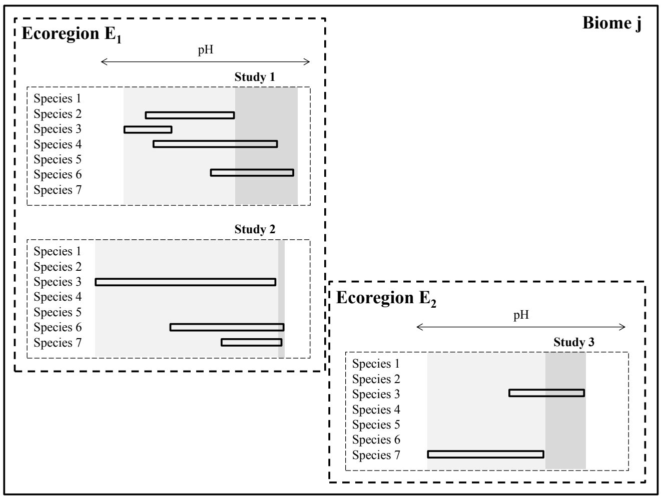

Figure S2.5.1 *Example of aggregation procedure in three different spatial resolution levels with seven hypothetical species occurrences. Sites (studies) 1 and 2, belong to ecoregion* E_1 *and site (study) 3 belongs to Ecoregion* E_2*. Both* E_1 *and* E_2 *are within biome j. The light and dark grey areas represent the pH values below and above the pH optimum, respectively. Note that, at the spatial resolution level of biome, all species with the exception of species 1, 5 and 6 are present. Additionally, species 7 is confirmed to occur at a broader pH range at the biome level rather than narrower ranges at the ecoregion and site levels. At an ecoregion resolution, species 6 does not occur in* E_2*. Likewise, at a site resolution, only a number of four species can occur within a single site.*

Table S2.5.1 *Total number of studies and species per ecoregion, the total number of species in the optimum pH, the pH range of species occurrence and the (range of) optimum pH ($SR_{opt,j}$) in* ***(a)*** *(sub)tropical moist broadleaf forests,* ***(b)*** *(sub)tropical grassland, savanna, and shrubland,* ***(c)*** *mangrove,* ***(d)*** *(sub)tropical dry broadleaf forests,* ***(e)*** *flooded grassland and savanna,* ***(f)*** *desert and xeric shrubland,* ***(g)*** *mediterranean forest, woodland, and shrubland,* ***(h)*** *temperate broadleaf mixed forest,* ***(i)*** *temperate grassland, savanna, and shrubland,* ***(j)*** *temperate coniferous forest,* ***(k)*** *montane grassland and shrubland,* ***(l)*** *boreal Forest / taiga, and* ***(m)*** *tundra and alpine.*

Ecoregion	**Studies**	**Species**	**$SR_{opt,j}$**	**pH range**	**(Range of) optimum pH**
(a) (Sub)tropical moist broadleaf forest					
Borneo lowand rain forests	2	38	30	3.7 to 4.6	4.0 to 4.1
Eastern Cordillera real montane forests	1	155	155	3.5 to 5.8	3.8 to 4.3
Isthmian-Atlantic mixed forests	1	1	1	4.8 to 6.9	4.8 to 6.9
Jian Nan subtropical evergreen forests	1	39	39	5.4 to 6.7	6.4 to 6.7
Luzon rain forests	1	11	10	4.4 to 7.2	4.9 to 5.0
Mato Grosso seasonal forests	1	69	69	3.4 to 4.3	3.5 to 3.8
Mount Cameroon and Bioko montane forests	1	53	50	4.9 to 5.8	5.3
Peninsular Malaysian rain forests	1	24	24	3.8 to 4.2	3.8 to 4.2
South Taiwan monsoon rain forests	1	50	50	4.1 to 4.7	4.2 to 4.7
Taiwan subtropical evergreen forest	1	65	65	3.0 to 5.6	3.7
Western Ecuador moist forest	1	14	14	5.9 to 6.4	5.9 to 6.4
(b) (Sub)tropical grassland, savanna, and shrubland					
Cerrado	3	131	107	4.5 to 6.1	4.9
(c) Mangrove					
Central African mangroves	1	21	21	3.4 to 7.1	4.1 to 5.8
Sunda Shelf mangroves	1	12	12	4.1 to 7.2	6.0 to 6.5
(d) (Sub)tropical dry broadleaf forest					
Yucatán dry forests	1	71	65	6.9 to 7.6	7.0
(e) Flooded grassland and savanna					
Pantanal	1	7	7	5.9 to 6.6	5.9 to 6.6
(f) Desert and xeric shrubland					
Alashan Plateau semi-desert	1	11	11	7.4 to 7.6	7.4 to 7.6
Baja California desert	1	27	26	6.0 to 7.7	6.9 to 7.0
Great Basin shrub steppe	1	1	1	9.6 to 9.7	9.6 to 9.7

Appendix S2.5

Ecoregion	Studies	Species	$SR_{opt,j}$	pH range	(Range of) optimum pH
Mojave desert	2	3	3	7.6 to 8.8	8.1 to 8.5
Northwestern thorn scrub forest	1	15	11	5.3 to 9.4	7.0 to 7.1
Sonoran desert	1	12	12	6.6 to 8.7	7.2 to 8.0
Southwestern Arabian foothills savanna	2	36	36	6.2 to 9.7	7.9 to 8.5
Taklimatan desert	1	18	17	6.1 to 10.5	7.4 to 7.8
Tehuacán Valley matorral	1	60	33	5.1 to 7.5	6.3 to 7.4
(g) Mediterranean Forest, Woodland, and Shrubland					
Iberian conifer forest	1	3	3	8.0 to 8.3	8.0 to 8.3
Lowland fynbos and renosterveld	1	14	9	4.9 to 7.9	5.4 to 5.5
Northeastern Spain and Southern France Mediterranean forests	1	6	6	6.4 to 6.7	6.5 to 6.7
(h) Temperate broadleaf mixed forest					
Appalachian mixed mesophytic forests	5	121	119	3.3 to 8.2	4.2
Appalachian-Blue Ridge forests	1	21	13	5.3 to 6.1	5.3 to 5.5
Atlantic mixed forests	8	234	230	2.4 to 8.4	5.2
Baltic mixed forest	4	81	57	3.2 to 8.0	5.0 to 5.9
Cantabrian mixed forests	2	19	19	4.2 to 5.6	4.8 to 4.9
Celtic broadleaf forest	1	3	3	7.1 to 8.1	7.5
Central European mixed forests	4	241	152	3.3 to 9.4	4.2 to 6.2
Central U.S. hardwood forests	1	6	6	6.1 to 6.6	6.3 to 6.4
Eastern Great Lakes lowland forests	1	10	10	4.1 to 5.9	4.1 to 5.9
Eastern Himalayan broadleaf forests	1	1	1	4.0 to 7.5	4.0 to 7.5
English Lowlands beech forests	1	52	52	5.1 to 6.6	5.8 to 5.9
New- England-Acadian forest	1	88	88	4.7 to 5.1	4.7 to 5.1
Northeastern coastal forests	2	15	15	3.3 to 7.1	4.3 to 4.9
Ozark Mountain forests	1	21	21	4.5 to 8.0	6.6 to 7.8
Sarmatic mixed forests	7	177	156	3.9 to 7.2	4.7
Taiheiyo montane deciduous forests	1	1	1	4.9 to 5.7	4.9 to 5.7
Western European broadleaf forests	4	70	61	3.8 to 8.7	5.1
Western Great Lakes forests	3	52	36	3.6 to 7.9	4.6
(i) Temperate grassland, savanna, and shrubland					
Alain-Western Tian Shan steppe	1	64	64	5.0 to 7.0	5.0 to 7.0
Central forest-grasslands transition	1	95	69	4.1 to 8.1	4.5 to 7.6
Mongolian-Manchurian grassland	1	25	25	7.0 to 7.6	7.3 to 7.5

Ecoregion	Studies	Species	$SR_{opt,j}$	pH range	(Range of) optimum pH
(j) Temperate Coniferous Forest					
Alps conifer and mixed forests	2	151	149	3.1 to 7.8	4.1 to 6.1
South Central Rockies forests	1	6	6	6.4 to 8.2	7.0
(k) Montane grassland and shrubland					
Eastern Himalayan alpine shrub and meadows	1	135	135	6.0 to 7.0	6.0 to 7.0
Ethiopian montane moorlands	1	4	4	5.5 to 6.2	5.5 to 6.0
(l) Boreal Forest / Taiga					
Eastern Canadian forest	1	33	33	5.3 to 6.9	6.8 to 6.9
Scandinavian and Russian taiga	3	62	56	3.2 to 7.7	5.1
(m) Tundra and alpine					
Artic foothills tundra	1	5	5	4.0 to 7.3	4.0 to 7.3
Scandinavian Montane Birch forest and grasslands	2	90	53	4.4 to 7.7	4.4 to 4.5

Table S2.5.2 *The optimum pH and the PNOF regressions coefficients* $\alpha^{\#}$ *and* $\beta^{\#}$ *(95% confidence interval in brackets) at the ecoregions of* ***(a)*** *(sub)tropical moist broadleaf forests,* ***(b)*** *(sub)tropical grassland, savanna, and shrubland,* ***(c)*** *mangrove,* ***(d)*** *(sub)tropical dry broadleaf forests,* ***(e)*** *flooded grassland and savanna,* ***(f)*** *desert and xeric shrubland,* ***(g)*** *mediterranean forest, woodland, and shrubland,* ***(h)*** *temperate broadleaf mixed forest,* ***(i)*** *temperate grassland, savanna, and shrubland,* ***(j)*** *temperate coniferous forest,* ***(k)*** *montane grassland and shrubland,* ***(l)*** *boreal Forest / taiga, and* ***(m)*** *tundra and alpine.*

Ecoregion	α	β	$R^{2\,£}$
(a) (Sub)tropical moist broadleaf forest			
Borneo lowand rain forests	$3.40^{¶,¥}$ (2.61 to 4.18)	$0.22^{¶,¥}$ (NS)	0.61
Eastern Cordillera real montane forests	3.65 (3.60 to 3.70)	0.08 (0.04 to 0.13)	0.93
Isthmian-Atlantic mixed forests	Model did not fit empirical data		
Jian Nan subtropical evergreen forests	6.15 (5.96 to 6.35)	0.29 (0.09 to 0.48)	0.64
Luzon rain forests	4.58 (4.51 to 4.65)	0.13 (0.06 to 0.21)	0.92
Mato Grosso seasonal forests	$3.38^{¶}$ (3.37 to 3.38)	$0.01^{¶}$ (0.006 to 0.009)	1.00
Mount Cameroon and Bioko montane forests	$5.02^{¥}$ (4.92 to 5.11)	$0.09^{¥}$ (NS)	0.88
Peninsular Malaysian rain forests	Model did not fit empirical data		

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Ecoregion	α	β	R^2[£]
South Taiwan monsoon rain forests	4.07[b] (4.06 to 4.08)	0.01[b] (0.008 to 0.01)	1.00
Taiwan subtropical evergreen forest	2.47[b] (1.72 to 3.22)	0.59[b] (0.04 to 1.14)	0.59
Western Ecuador moist forest	Model did not fit empirical data		
(b) (Sub)tropical grassland, savanna, and shrubland			
Cerrado	4.55[¥] (4.40 to 4.70)	0.16[¥] (NS)	0.82
(c) Mangrove			
Central African mangroves	3.33[¶] (3.58 to 3.67)	0.24[¶] (0.19 to 0.29)	0.94
Sunda Shelf mangroves	4.20 (4.16 to 4.24)	0.08 (0.04 to 0.12)	0.79
(d) (Sub)tropical dry broadleaf forest			
Yucatán dry forests	Model did not fit empirical data		
(e) Flooded grassland and savanna			
Pantanal	2.97[¶,¥] (NS)	0.20[¶,¥] (NS)	
(f) Desert and xeric shrubland			
Alashan Plateau semi-desert	Model did not fit empirical data		
Baja California desert	6.29 (6.20 to 6.38)	0.16 (0.07 to 0.26)	0.87
Great Basin shrub steppe	Model did not fit empirical data		
Mojave desert	Model did not fit empirical data		
Northwestern thorn scrub forest	6.38 (6.28 to 6.47)	0.33 (0.24 to 0.43)	0.91
Sonoran desert	5.63[¶] (4.93 to 6.32)	0.45[¶] (0.19 to 0.71)	0.71
Southwestern Arabian foothills savanna	5.81[¶] (5.54 to 6.08)	0.72[¶] (0.52 to 0.92)	0.83
Taklimatan desert	6.4 (6.30 to 6.50)	0.24 (0.14 to 0.35)	0.83
Tehuacán Valley matorral	Model did not fir empirical data		
(g) Mediterranean Forest, Woodland, and Shrubland			
Iberian conifer forest	Model did not fir empirical data		
Lowland fynbos and renosterveld	5.30[¥] (5.20 to 5.40)	0.07[¥] (NS)	0.78
Northeastern Spain and Southern France Mediterranean forests	6.41 (6.41 to 6.41)	0.006 (0.002 to 0.010)	0.99
(h) Temperate broadleaf mixed forest			
Appalachian mixed mesophytic forests	3.78 (3.76 to 3.80)	0.04 (0.01 to 0.06)	0.98
Appalachian-Blue Ridge forests	Model did not fit empirical data		
Atlantic mixed forests	3.33 (3.22 to 3.44)	0.49 (0.39 to 0.60)	0.91

Ecoregion	α	β	R^{2} [£]
Baltic mixed forest	3.92 (3.71 to 4.12)	0.78 (0.46 to 1.11)	0.69
Cantabrian mixed forests	2.58[¶,¥] (0.14 to 5.02)	0.64[¶,¥] (NS)	0.45
Celtic broadleaf forest	7.17[¥] (7.00 to 7.34)	0.16[¥] (NS)	0.77
Central European mixed forests	3.43 (2.90 to 3.95)	1.21 (0.64 to 1.78)	0.43
Central U.S. hardwood forests	3.43[¶,¥] (2.90 to 3.95)	0.11[¶,¥] (NS)	0.73
Eastern Great Lakes lowland forests	Model did not fit empirical data		
Eastern Himalayan broadleaf forests	Model did not fit empirical data		
English Lowlands beech forests	4.01[¶,¥] (2.33 to 5.69)	0.72[¶,¥] (NS)	0.43
North Island temperate forests	Model did not fit empirical data		
Northeastern coastal forests	4.12 (4.04 to 4.21)	0.15 (0.08 to 0.23)	0.91
Ozark Mountain forests	5.58 (5.44 to 5.72)	0.64 (0.50 to 0.78)	0.88
Sarmatic mixed forests	4.2 (4.16 to 4.24)	0.15 (0.11 to 0.19)	0.98
Taiheiyo montane deciduous forests	Model did not fit empirical data		
Western European broadleaf forests	4.38 (4.31 to 4.46)	0.20 (0.14 to 0.27)	0.93
Western Great Lakes forests	4.25 (4.11 to 4.39)	0.30 (0.14 to 0.47)	0.76
(i) Temperate grassland, savanna, and shrubland			
Alain-Western Tian Shan steppe	Model did not fit empirical data		
Central forest-grasslands transition	-49.23[¶,¥] (NS)	93.37[¶,¥] (NS)	0.00
Mongolian-Manchurian grassland	7.02[¥] (6.84 to 7.21)	0.15[¥] (NS)	0.72
(j) Temperate Coniferous Forest			
Alps conifer and mixed forests	3.26 (3.24 to 3.27)	0.03 (0.02 to 0.04)	0.95
South Central Rockies forests	6.09[¶,¥] (5.02 to 7.16)	0.65[¶,¥] (NS)	0.33
(k) Montane grassland and shrubland			
Eastern Himalayan alpine shrub and meadows	3.18[¶,¥] (NS)	0.20[¶,¥] (NS)	
Ethiopian montane moorlands	2.38[¶,¥] (NS)	0.21[¶,¥] (NS)	
(l) Boreal Forest / Taiga			
Eastern Canadian forest	3.97[¶] (3.53 to 4.41)	0.74[¶] (0.55 to 0.93)	0.88
Scandinavian and Russian taiga	3.78 (3.73 to 3.85)	0.38 (0.32 to 0.44)	0.96
(m) Tundra and alpine			
Artic foothills tundra	Model did not fit empirical data		
Scandinavian Montane Birch forest and grasslands	Model did not fit empirical data		

[#] The 95% confidence interval around α and β is shown in parenthesis

[¶] α is not within the range pH values used in the regression (as reported in Table S2.5.1)

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Ecoregion	α	β	R^{2}[£]

[¥] Coefficient not included in the sensitivity analysis because their results are based on one (or both) coefficient non-different than zero (NS)

[£] $Pseudo - R^{2} = 1 - \frac{SS_{residual}}{SS_{Corrected\,Total}}$, as defined by Schabenberger and Pierce (2001)

Table S2.5.3 *The optimum pH and the PNOF regressions coefficients α*[#] *and* [#] *(95% confidence interval in brackets) of studies of* ***(a)*** *(sub)tropical moist broadleaf forests,* ***(b)*** *(sub)tropical grassland, savanna, and shrubland,* ***(c)*** *mangrove,* ***(d)*** *(sub)tropical dry broadleaf forests,* ***(e)*** *flooded grassland and savanna,* ***(f)*** *desert and xeric shrubland,* ***(g)*** *mediterranean forest, woodland, and shrubland,* ***(h)*** *temperate broadleaf mixed forest,* ***(i)*** *temperate grassland, savanna, and shrubland,* ***(j)*** *temperate coniferous forest,* ***(k)*** *montane grassland and shrubland,* ***(l)*** *boreal Forest / taiga, and* ***(m)*** *tundra and alpine.*

Study	α	β	R^{2}[£]
(a) (Sub)tropical moist broadleaf mixed forest			
Banack *et al.* (2002)		Model did not fit empirical data	
Banaticla & Buot (2005)	4.58 (4.51 to 4.65)	0.13 (0.06 to 0.21)	0.92
Chen *et al.* (1997)	4.07[¶] (4.07 to 4.07)	0.0081[¶] (0.008 to 0.009)	1.00
Haro-Carrión *et al.* (2009)		Model did not fit empirical data	
Homeier *et al.* (2010)	3.65 (3.6 to 3.7)	0.08 (0.04 to 0.13)	0.93
Hsieh *et al.* (1998)	2.48[¶] (1.75 to 3.2)	0.58[¶] (0.05 to 1.11)	0.60
Ivanauskas *et al.* (2003)	3.38[¶] (3.37 to 3.38)	0.008[¶] (0.007 to 0.010)	1.00
Lesueur *et al.* (1993)		Model did not fit empirical data	
Paoli *et al.* (2006)		Model did not fit empirical data	
Penfold & Lamb (2002)		Model did not fit empirical data	
Poulsen (1996)	3.39[¶,¥] (2.59 to 4.18)	0.22[¶,¥] (NS)	0.62
Proctor *et al.* (2007)	5.01[¥] (4.91 to 5.11)	0.09[¥] (NS)	0.88
Siebert (2005)		Model did not fit empirical data	
Teo *et al.* (2003)		Model did not fit empirical data	
Turner *et al.* (1995)		Model did not fit empirical data	
Vetaas (1997)		Model did not fit empirical data	
Zhang *et al.* (2001)	6.15 (5.95 to 6.35)	0.29 (0.09 to 0.49)	0.64
(b) (Sub)tropical grassland, savanna, and shrubland			
Amorim & Batalha (2007)	4.82[¥] (4.75 to 4.9)	0.05[¥] (NS)	0.90
da Silva & Batalha (2008)	4.34[¶,¥] (1.51 to 7.18)	0.14[¶,¥] (NS)	0.61
Neto *et al.* (1999)		Model did not fit empirical data	
(c) Mangrove			

Study	α	β	R^2[£]
Ashton & Macintosh (2002)	4.2 (4.16 to 4.24)	0.08 (0.04 to 0.12)	0.79
Ukpong (1995)	3.63 (3.58 to 3.67)	0.24 (0.19 to 0.29)	0.94
(d) (Sub)tropical dry broadleaf forest			
de Souza *et al.* (2007)		Model did not fit empirical data	
Dubbin *et al.* (2006)	6.15 (6.03 to 6.26)	0.49 (0.34 to 0.63)	0.94
White & Hood (2004)		Model did not fit empirical data	
(e) Flooded grassland and savanna			
Haase (1999)		Model did not fit empirical data	
Ssegawa *et al.* (2004)		Model did not fit empirical data	
(f) Desert and xeric shrubland			
El-Ghani (1998)	6.56[b] (6.56 to 6.56)	0.04[¶] (0.04 to 0.05)	1.00
Camargo-Ricalde *et al.* (2002)		Model did not fit empirical data	
El-Demerdash *et al.* (1994)	5.86[¶] (5.54 to 6.17)	0.79[¶] (0.53 to 1.05)	0.80
El-Demerdash *et al.* (1995)	5.87[¶] (5.62 to 6.12)	0.68[¶] (0.49 to 0.86)	0.84
Franco-Vizcaíno *et al.* (1993)	6.29 (6.19 to 6.39)	0.16 (0.07 to 0.26)	0.87
Kabir *et al.* (2010)	6.37 (6.28 to 6.47)	0.34 (0.25 to 0.43)	0.91
Li *et al.* (2008)		Model did not fit empirical data	
Mahmood *et al.* (1994)		Model did not fit empirical data	
Parker (1991)	5.6[¶] (4.89 to 6.31)	0.45[¶] (0.19 to 0.72)	0.71
Pettit & Naiman (2007)		Model did not fit empirical data	
Shaltout *et al.* (1997)	7.16 (7.14 to 7.19)	0.09 (0.06 to 0.11)	0.99
Titus *et al.* (2002)	7.86 (7.81 to 7.91)	0.1 (0.05 to 0.15)	0.93
Toft & Elliot-Fisk (2002)		Model did not fit empirical data	
Walker *et al.* (2001)		Model did not fit empirical data	
Zhang *et al.* (2005)	6.4 (6.3 to 6.5)	0.23 (0.13 to 0.34)	0.83
(g) Mediterranean Forest, Woodland, and Shrubland			
Navas *et al.* (2008)	7 (6.84 to 7.16)	0.37 (0.21 to 0.53)	0.77
Richards *et al.* (1997)	5.3[¥] (5.2 to 5.39)	0.07[¥] (NS)	0.78
Römermann *et al.* (2005)	6.41 (6.41 to 6.41)	0.006 (0.004 to 0.007)	0.99
Ruecker *et al.* (1998)		Model did not fit empirical data	
(h) Temperate broadleaf mixed forest			
Abrams & Hayes (2008)		Model did not fit empirical data	

Appendix S2.5

Study	**α**	**β**	**$R^{2\pounds}$**
Ahokas (1997)	3.72 (3.69 to 3.75)	0.15 (0.12 to 0.18)	0.97
Akbar *et al.* (2009)	7.17$^{\yen}$ (7 to 7.34)	0.16$^{\yen}$ (NS)	0.77
Andersson (1992)		Model did not fitempirical data	
Arii & Lechowicz (2002)		Model did not fit empirical data	
Baeten *et al.* (2009)	2.5¶ (2.16 to 2.84)	0.42¶ (0.25 to 0.59)	0. 77
Bellemare *et al.* (2005)		Model did not fit empirical data	
Bernard & Seischab (1995)		Model did not fit empirical data	
Bigelow & Canham (2002)	3.76 (3.71 to 3.8)	0.21 (0.16 to 0.25)	0.95
Bjørnstad (1991)		Model did not fit empirical data	
Brosofske *et al.* (2001)	3.35¶ (3.14 to 3.56)	0.32¶ (0.17 to 0.47)	0.85
Brunet *et al.* (1996)	4.12 (4.08 to 4.16)	0.09 (0.05 to 0.13)	0.96
Brunet *et al.* (1997a)	4.12$^{\P, \yen}$ (-1.83 to 10.07)	0.16$^{b, \yen}$ (NS)	0.46
Brunet *et al.* (1997b)	4.33¶ (3.94 to 4.72)	0.3¶ (0.04 to 0.56)	0.72
Chapman & Bannister (1995)		Model did not fit empirical data	
Cole & Weltzin (2004)		Model did not fit empirical data	
Coudun & Gégout (2007)		Model did not fit empirical data	
Coudun *et al.* (2006)		Model did not fit empirical data	
Dambrine *et al.* (2007)		Model did not fit empirical data	
De Graaf *et al.* (2009)	4.14 (4.07 to 4.2)	0.24 (0.17 to 0.31)	0.94
Dick & Gilliam (2007)		Model did not fit empirical data	
Diekmann & Lawesson (1999)	3.76¶ (3.63 to 3.89)	0.32¶ (0.23 to 0.41)	0.81
Dzwonko (2001)	4.19 (4.18 to 4.2)	0.07 (0.06 to 0.08)	1.00
Emerson *et al.* (2009)		Model did not fit empirical data	
Falkengren-Grerup *et al.* (1998)		Model did not fit empirical data	
Fennema (1992)	2.93 (2.9 to 2.96)	0.09 (0.06 to 0.12)	0.87
Gillian & Turrill (1993)		Model did not fit empirical data	
Graae (2000)	4.09¶ (4.09 to 4.09)	0.007¶ (0.005 to 0.009)	1.00
Graae *et al.* (2003)	3.27¶ (3.27 to 3.27)	0.009¶ (0.008 to 0.009)	1.00
Härdtle *et al.* (2005)	2.33¶ (2.27 to 2.4)	0.08¶ (0.03 to 0.13)	0.87
Hofmeister *et al.* (2009)	3.66 (3.54 to 3.77)	0.25 (0.13 to 0.38)	0.84
Hutchinston *et al.* (1999)	2.69$^{\P,\yen}$ (NS)	0.47$^{\P,\yen}$ (NS)	0.36
Jacob *et al.* (2009)	1.37$^{\P,\yen}$ (NS)	2.24$^{\P,\yen}$ (0.45 to 4.03)	0.32
Kooijman (2010)	4.07¶ (3.76 to 4.37)	0.68¶ (0.44 to 0.92)	0.76
Lang *et al.* (2009)	4.52$^{\yen}$ (3.37 to 5.68)	0.01$^{\yen}$ (NS)	0.96
Lukešová & Hoffmann (1996)	4.01 (3.34 to 4.68)	2.31 (0.75 to 3.88)	0.31
Petersen (1994)	4.8 (4.76 to 4.84)	0.07 (0.03 to 0.11)	0.86

Study	α	β	R^2[£]
Piernik (2005)	6.13 (6.07 to 6.2)	0.09 (0.03 to 0.14)	0.93
Plue *et al.* (2008)	3.73 (3.42 to 4.03)	1.00 (0.68 to 1.32)	0.70
Plue *et al.* (2009)		Model did not fit empirical data	
Roberts & Gilliam (1995)		Model did not fit empirical data	
Sage *et al.* (2005)	4.04[¶,¥] (2.39 to 5.69)	0.72[¶,¥] (NS)	0.43
Skousen *et al.* (1994)	2.71[¶] (2.43 to 3.00)	0.53[¶] (0.37 to 0.69)	0.86
Tyler (1996)	4.21 (4.16 to 4.26)	0.07 (0.01 to 0.12)	0.95
Van Couwenberghe *et al.* (2010)		Model did not fit empirical data	
Van Rossum *et al.* (1999)		Model did not fit empirical data	
Verheyen & Hermy (2001)		Model did not fit empirical data	
Vetaas (2000)		Model did not fit empirical data	
Ware *et al.* (1992)	5.58 (5.44 to 5.72)	0.66 (0.50 to 0.79)	0.87
West *et al.* (2009)	6.05[¶,¥] (5.7 to 6.39)	0.11[¶,¥] (NS)	0.73
Xu & Inubushi (2009)		Model did not fit empirical data	
Zas & Alonso (2002)	2.48[¶,¥] (NS)	0.64[¶,¥] (NS)	0.45
(i) Temperate grassland, savanna, and shrubland			
Baasch *et al.* (2009)	2.98 (2.92 to 3.03)	0.2 (0.14 to 0.25)	0.87
Beumer *et al.* (2008)		Model did not fit empirical data	
Dollar *et al.* (1992)	2.86[¶,¥] (NS)	0.91[¶,¥] (NS)	0.10
Heikens & Robertson (1995)		Model did not fit empirical data	
Mårtensson & Olsson (2010)	4.45[¶] (4.2 to 4.71)	0.77[¶] (0.55 to 0.98)	0.77
Olsson *et al.* (2009)	4.9[¥] (4.06 to 5.73)	1.30[¥] (NS)	0.00
Reinhammar *et al.* (2002)		Model did not fit empirical data	
Rodríguez *et al.* (1995)	4.9[¶,¥] (4.06 to 5.73)	1.3[¶,¥] (NS)	0.29
Roem & Berendse (2000)	5.04 (4.99 to 5.09)	0.04 (0.0003 to 0.08)	0.88
Sebastiá (2004)		Model did not fit empirical data	
Spiegelberger *et al.* (2006)		Model did not fit empirical data	
Stevens *et al.* (2010)		Model did not fit empirical data	
Tyler (2000)	3.82[¶] (3.54 to 4.1)	0.61[¶] (0.45 to 0.76)	0.86
Wagner (2009)		Model did not fit empirical data	
Walker *et al.* (2004)	-1.06[¶,¥] (NS)	2.45[¶,¥] (NS)	0.21
Zuo *et al.* (2009)	7.02[¥] (6.84 to 7.21)	0.15[¥] (NS)	0.72
(j) Temperate Coniferous Forest			
Dimopoulos *et al.* (1996)	6.58 (6.29 to 6.86)	0.96 (0.61 to 1.31)	0.65
Goldin (2001)	6.09[¶,¥] (5.02 to 7.16)	0.65[¶,¥] (NS)	0.33

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Study	α	β	$R^{2£}$
Hülber *et al.* (2008)	2.3[b] (1.97 to 2.62)	0.23[b] (0.16 to 0.3)	0.81
Johnston & Johnston (2004)		Model did not fit empirical data	
Kutnar & Martinčič (2003)	3.33 (3.26 to 3.4)	0.22 (0.15 to 0.3)	0.85
Nygaard & Abrahamsen (1991)		Model did not fit empirical data	
Nygaard & Ødegaard (1999)		Model did not fit empirical data	
Totland & Nylehn (1998)		Model did not fit empirical data	
(k) Montane grassland and shrubland			
Baniya *et al.* (2009)		Model did not fit empirical data	
Yimer *et al.* (2006)		Model did not fit empirical data	
(l) Boreal Forest / Taiga			
Elgersma & Dhillion (2002)	3.72 (3.64 to 3.8)	0.39 (0.29 to 0.49)	0.92
Giesler *et al.* (1998)	3.68[¶] (3.55 to 3.81)	0.31[¶] (0.17 to 0.45)	0.79
Karim & Mallik (2008)	3.97[¶] (3.53 to 4.41)	0.74[¶] (0.55 to 0.93)	0.88
Koptsik *et al.* (2001)	5.02[¥] (4.8 to 5.25)	0.02[¥] (NS)	0.95
(m) Tundra and alpine			
Arnesen *et al.* (2007)	5.34 (5.11 to 5.57)	0.78 (0.53 to 1.03)	0.74
Auerbach *et al.* (1997)		Model did not fit empirical data	
Austrheim *et al.* (2005)		Model did not fit empirical data	
Razzhivin (1994)	4.77 (4.67 to 4.86)	0.32 (0.22 to 0.43)	0.87
Walker (2000)		Model did not fit empirical data	
Walker & Everett (1991)	6.87[¶,¥] (6.45 to 7.19)	0.19[¶,¥] (NS)	0.62

[#] The 95% confidence interval around α and β is shown in parenthesis

[¶] α is not within the range pH values used in the regression

[¥] Coefficient not included in the sensitivity analysis because their results are based on one (or both) coefficient non-different than zero (NS)

[£] $Pseudo-R^2 = 1 - \frac{SS_{residual}}{SS_{Corrected\,Total}}$, as defined by Schabenberger & Pierce (2001)

Appendix S3.1 Biome-specific log-logistic coefficients.

Table S3.1.1 *Coefficients α and β (95% confidence interval) of the PNOF – pH function used to derive effect factors*

Biomes	**α**	**β**
Tundra	4.63 (4.61 to 4.65)	0.32 (0.29 to 0.35)
Boreal forest / Taiga	4.37 (4.31 to 4.44)	0.44 (0.38 to 0.50)
Temperate conifer forests	3.41 (3.29 to 3.52)	1.16 (0.93 to 1.39)
Temperate broadleaf and mixed forests	3.95 (3.94 to 3.96)	0.58 (0.56 to 0.59)
Montane grasslands and shrublands	5.91 (5.9 to 5.93)	0.02 (0.01 to 0.02)
Temperate grasslands, savannas and shrublands	4.69 (4.61 to 4.76)	0.88 (0.76 to 1.0)
Mediterranean forests, woodlands and scrub	6.04 (5.48 to 6.61)	1.3 (0.64 to 1.96)
Desert and xeric shrublands	6.79 (6.78 to 6.79)	0.29 (0.29 to 0.3)
(Sub)tropical moist broadleaf forest	4.11 (4.07 to 4.15)	0.70 (0.65 to 0.75)
(Sub)tropical grasslands, savannas and shrublands	4.73 (4.71 to 4.76)	0.07 (0.05 to 0.09)
(Sub)tropical coniferous forests#	3.55	0.18
(Sub)tropical dry broadleaf forests#	3.55	0.18
Flooded grasslands and savannas	6.8 (6.79 to 6.81)	0.28 (0.27 to 0.29)
Mangroves	3.87 (3.73 to 4.0)	0.16 (0.06 to 0.26)

Biomes whose coefficients were approximated by other biomes based on similar climate conditions

Appendix S3.2 Characterization factors

Table S3.2.1 *Global atmospheric fate factors ($\sum FF$), midpoint characterization factors ($\sum FF \cdot SF$), and endpoint characterization factors ($\sum FF \cdot SF \cdot EF$).*

$\sum FF$ (keq·kg^{-1})			$\sum FF \cdot SF$ (mol H·m^2·yr·kg^{-1})			$\sum FF \cdot SF \cdot EF$ (m^2·yr·kg^{-1})		
NO_x	NH_3	SO_2	NO_x	NH_3	SO_2	NO_x	NH_3	SO_2
4.18×10^{-9}	1.10×10^{-8}	6.08×10^{-9}	9.17×10^{-4}	4.93×10^{-3}	2.52×10^{-3}	7.9	28.4	16.4

Table S3.2.2 *Continent-specific atmospheric fate factors ($\sum FF$), midpoint characterization factors ($\sum FF \cdot SF$), and endpoint characterization factors ($\sum FF \cdot SF \cdot EF$).*

	$\sum FF$ (keq·kg^{-1})			$\sum FF \cdot SF$ (mol H·m^2·yr·kg^{-1})			$\sum FF \cdot SF \cdot EF$ (m^2·yr·kg^{-1})		
Continent	NO_x	NH_3	SO_2	NO_x	NH_3	SO_2	NO_x	NH_3	SO_2
NorthAmerica	4.18×10^{-9}	1.21×10^{-8}	6.25×10^{-9}	1.50×10^{-3}	1.57×10^{-2}	4.32×10^{-3}	8.02×10^{0}	66.1	22.7
SouthAmerica	3.20×10^{-9}	1.02×10^{-8}	5.46×10^{-9}	7.22×10^{-4}	5.21×10^{-3}	3.46×10^{-3}	6.70×10^{0}	40.6	16.4
Europe	4.87×10^{-9}	1.32×10^{-8}	7.31×10^{-9}	1.57×10^{-3}	8.02×10^{-3}	4.44×10^{-3}	9.76×10^{0}	46.9	29.4
Asia	3.93×10^{-9}	1.01×10^{-8}	5.94×10^{-9}	1.45×10^{-3}	5.37×10^{-3}	3.59×10^{-3}	8.61×10^{0}	25.2	23.0
Australia	3.03×10^{-9}	9.92×10^{-9}	5.38×10^{-9}	6.23×10^{-4}	2.87×10^{-3}	2.40×10^{-3}	10.8×10^{1}	36.1	31.5
Oceania	3.32×10^{-9}	1.08×10^{-8}	5.70×10^{-9}	3.01×10^{-4}	8.52×10^{-4}	7.08×10^{-4}	2.96×10^{0}	10.1	8.76

Table S3.2.1 *Country-specific atmospheric fate factors ($\sum FF$), midpoint characterization factors ($\sum FF \cdot SF$), and endpoint characterization factors ($\sum FF \cdot SF \cdot EF$).*

	$\sum FF$ (keq·kg^{-1})			$\sum FF \cdot SF$ (mol H·m^2·yr·kg^{-1})			$\sum FF \cdot SF \cdot EF$ (m^2·yr·kg^{-1})		
Country	**NO_x**	**NH_3**	**SO_2**	**NO_x**	**NH_3**	**SO_2**	**NO_x**	**NH_3**	**SO_2**
Afghanistan	3.73E-09	1.05E-08	5.94E-09	2.21E-03	8.09E-03	5.47E-03	1.26E+01	4.66E+01	4.02E+01
Albania	4.25E-09	1.21E-08	6.59E-09	1.32E-03	6.02E-03	3.22E-03	9.05E+00	3.67E+01	2.42E+01
Algeria	3.75E-09	1.13E-08	6.10E-09	5.80E-04	2.34E-03	1.16E-03	8.47E+00	4.01E+01	3.51E+01
American Samoa	3.74E-09	9.80E-09	5.06E-09	1.81E-05	1.53E-05	2.07E-05	1.26E-01	1.05E-01	1.64E-01
Andorra	4.34E-09	1.26E-08	6.81E-09	1.39E-03	7.85E-03	3.64E-03	1.06E+01	5.72E+01	3.01E+01
Angola	2.90E-09	9.79E-09	5.16E-09	7.34E-04	2.65E-03	2.88E-03	1.09E+01	3.94E+01	5.53E+01
Anguilla	3.22E-09	1.05E-08	5.51E-09	1.63E-04	1.47E-03	4.32E-04	1.32E+00	9.55E+00	3.34E+00
Antarctica	4.22E-09	1.83E-08	9.47E-09	1.51E-04	8.48E-05	6.41E-05	1.15E+00	6.23E-01	5.83E-01
Antigua & Barbuda	2.84E-09	1.05E-08	5.54E-09	1.43E-04	1.48E-03	4.48E-04	1.13E+00	9.50E+00	3.37E+00
Argentina	3.51E-09	1.16E-08	5.78E-09	3.56E-04	1.69E-03	2.50E-03	2.47E+00	1.20E+01	1.16E+01
Armenia	4.28E-09	1.14E-08	6.60E-09	1.79E-03	7.86E-03	4.70E-03	1.03E+01	4.37E+01	3.03E+01
Aruba	3.22E-09	1.00E-08	5.23E-09	2.27E-04	1.56E-03	4.30E-04	2.49E+00	1.68E+01	4.40E+00
Australia	3.32E-09	1.08E-08	5.70E-09	3.51E-04	1.09E-03	7.08E-04	2.55E+00	8.48E+00	8.15E+00
Austria	4.79E-09	1.34E-08	7.29E-09	2.33E-03	1.61E-02	6.41E-03	1.14E+01	6.65E+01	3.11E+01
Azerbaijan	4.32E-09	1.13E-08	6.60E-09	1.66E-03	6.43E-03	3.76E-03	9.52E+00	3.49E+01	2.61E+01
Bahamas	3.20E-09	1.08E-08	5.74E-09	3.84E-04	3.42E-03	1.00E-03	2.07E+00	1.68E+01	5.41E+00
Bahrain	3.48E-09	1.05E-08	5.54E-09	1.67E-03	4.71E-03	2.97E-03	5.99E+00	2.35E+01	1.42E+01
Bangladesh	3.45E-09	1.04E-08	5.51E-09	8.04E-04	1.65E-03	1.48E-03	5.58E+00	1.09E+01	1.07E+01
Barbados	3.12E-09	1.03E-08	5.40E-09	1.68E-04	1.45E-03	4.59E-04	1.50E+00	1.04E+01	3.64E+00
Belarus	5.08E-09	1.36E-08	7.76E-09	1.51E-03	6.00E-03	5.14E-03	1.05E+01	4.97E+01	3.49E+01
Belgium	4.92E-09	1.40E-08	7.67E-09	1.87E-03	1.15E-02	5.06E-03	9.98E+00	6.03E+01	2.63E+01

	$\sum FF$ (keq·kg^{-1})			$\sum FF \cdot SF$ (mol H·m^{2}·yr·kg^{-1})			$\sum FF \cdot SF \cdot EF$ (m^{2}·yr·kg^{-1})		
Country	**NO_x**	**NH_3**	**SO_2**	**NO_x**	**NH_3**	**SO_2**	**NO_x**	**NH_3**	**SO_2**
Belize	3.26E-09	1.02E-08	5.39E-09	2.55E-04	1.96E-03	8.20E-04	2.26E+00	1.48E+01	6.22E+00
Benin	3.16E-09	9.89E-09	5.27E-09	3.19E-04	1.41E-03	1.68E-03	3.48E+00	1.29E+01	2.03E+01
Bhutan	3.55E-09	1.04E-08	5.59E-09	1.21E-03	5.78E-03	3.38E-03	8.17E+00	2.93E+01	2.08E+01
Bolivia	3.26E-09	9.98E-09	5.38E-09	5.78E-04	3.10E-03	5.25E-03	4.26E+00	2.57E+01	1.80E+01
Bosnia Herzegovina	4.47E-09	1.28E-08	6.91E-09	1.79E-03	1.06E-02	4.88E-03	1.04E+01	5.69E+01	2.82E+01
Botswana	3.03E-09	1.02E-08	5.50E-09	8.28E-04	3.10E-03	2.80E-03	6.27E+00	2.51E+01	2.91E+01
Brazil	3.13E-09	1.00E-08	5.28E-09	7.34E-04	4.21E-03	3.18E-03	0.00E+00	4.21E+01	2.82E+01
British Indian Ocean Territory	2.43E-09	9.69E-09	5.12E-09	1.00E-04	3.00E-04	1.81E-04	7.24E+00	2.11E+00	1.50E+00
British Virgin Isl.	3.22E-09	1.05E-08	5.51E-09	1.63E-04	1.47E-03	4.32E-04	6.31E-01	9.55E+00	3.34E+00
Brunei	2.74E-09	9.68E-09	5.15E-09	3.14E-04	8.12E-04	7.09E-04	1.32E+00	5.46E+00	4.96E+00
Bulgaria	4.43E-09	1.23E-08	6.71E-09	1.35E-03	4.79E-03	2.75E-03	2.01E+00	3.68E+01	2.73E+01
Burkina Faso	3.18E-09	1.00E-08	5.34E-09	3.55E-04	1.85E-03	1.80E-03	9.90E+00	1.91E+01	2.59E+01
Burundi	2.67E-09	9.66E-09	5.13E-09	5.96E-04	3.14E-03	3.36E-03	3.76E+00	3.01E+01	5.08E+01
Cambodia	3.02E-09	9.88E-09	5.32E-09	4.51E-04	1.13E-03	1.01E-03	7.61E+00	2.20E+01	1.61E+01
Cameroon	2.80E-09	9.77E-09	5.17E-09	6.13E-04	2.79E-03	2.74E-03	4.72E+00	2.69E+01	2.70E+01
Canada	4.78E-09	1.33E-08	7.05E-09	2.15E-03	1.61E-02	7.99E-03	7.17E+00	7.84E+01	3.76E+01
Cape Verde	2.95E-09	1.02E-08	5.31E-09	1.16E-04	1.25E-03	5.54E-04	1.04E+01	9.01E+00	4.17E+00
Central African Republic	3.06E-09	9.75E-09	5.20E-09	1.31E-03	4.94E-03	4.72E-03	8.31E-01	8.32E+01	7.77E+01
Chad	3.06E-09	9.94E-09	5.28E-09	7.99E-04	3.41E-03	3.59E-03	2.25E+01	3.15E+01	4.43E+01
Chile	3.56E-09	1.21E-08	5.74E-09	7.85E-04	6.07E-03	3.57E-03	1.13E+01	2.81E+01	1.14E+01
China	3.98E-09	1.00E-08	5.81E-09	1.60E-03	5.78E-03	3.91E-03	4.11E+00	3.10E+01	2.30E+01
Christmas Isl.	2.34E-09	9.69E-09	5.13E-09	1.59E-04	4.34E-04	4.14E-04	9.07E+00	2.86E+00	2.56E+00
Colombia	3.08E-09	9.69E-09	5.11E-09	4.35E-04	3.24E-03	1.21E-03	4.39E+00	3.69E+01	8.29E+00

	$\sum FF$ (keq·kg^{-1})			$\sum FF \cdot SF$ (mol H·m^2·yr·kg^{-1})			$\sum FF \cdot SF \cdot EF$ (m^2·yr·kg^{-1})		
Country	**NO$_x$**	**NH$_3$**	**SO$_2$**	**NO$_x$**	**NH$_3$**	**SO$_2$**	**NO$_x$**	**NH$_3$**	**SO$_2$**
Congo	2.30E-09	9.65E-09	5.11E-09	6.60E-04	4.83E-03	4.10E-03	7.37E+00	4.91E+01	5.96E+01
Congo DRC	2.63E-09	9.69E-09	5.16E-09	6.84E-04	2.77E-03	4.80E-03	9.99E+00	3.64E+01	9.21E+01
Comoros	2.82E-09	9.79E-09	5.14E-09	3.65E-04	1.06E-03	9.82E-04	4.41E+00	1.10E+01	1.43E+01
Cook Isl.	4.00E-09	1.01E-08	5.33E-09	2.36E-05	4.81E-06	8.68E-06	1.69E-01	3.15E-02	5.89E-02
Costa Rica	3.34E-09	9.87E-09	5.15E-09	3.88E-04	3.79E-03	1.86E-03	2.62E+00	2.06E+01	8.77E+00
Cote d'Ivoire	3.07E-09	9.82E-09	5.24E-09	2.89E-04	1.89E-03	1.53E-03	2.65E+00	1.57E+01	1.74E+01
Croatia	4.61E-09	1.30E-08	7.08E-09	1.88E-03	1.04E-02	4.41E-03	1.03E+01	5.31E+01	2.57E+01
Cuba	3.20E-09	1.05E-08	5.58E-09	2.67E-04	2.31E-03	7.91E-04	2.24E+00	1.87E+01	7.18E+00
Cyprus	3.91E-09	1.10E-08	6.08E-09	1.03E-03	2.36E-03	1.43E-03	8.18E+00	2.83E+01	1.94E+01
Czech Republic	4.95E-09	1.37E-08	7.53E-09	2.45E-03	1.69E-02	6.99E-03	1.24E+01	8.61E+01	3.62E+01
Denmark	5.19E-09	1.43E-08	8.07E-09	2.01E-03	1.26E-02	6.16E-03	8.84E+00	4.87E+01	2.41E+01
Djibouti	2.82E-09	9.96E-09	5.24E-09	5.54E-04	1.80E-03	1.27E-03	5.80E+00	1.79E+01	1.41E+01
Dominican Republic	3.21E-09	1.04E-08	5.45E-09	1.82E-04	1.47E-03	3.94E-04	1.55E+00	1.12E+01	3.71E+00
Ecuador	3.32E-09	9.57E-09	5.07E-09	6.17E-04	4.45E-03	2.28E-03	4.26E+00	3.01E+01	1.50E+01
Egypt	3.59E-09	1.03E-08	5.72E-09	1.80E-03	3.78E-03	5.18E-03	9.76E+00	2.78E+01	2.47E+01
El Salvador	3.30E-09	1.00E-08	5.27E-09	2.88E-04	2.15E-03	9.42E-04	3.07E+00	2.42E+01	8.62E+00
Equatorial Guinea	2.31E-09	9.69E-09	5.15E-09	5.50E-04	4.45E-03	2.52E-03	4.79E+00	3.22E+01	2.36E+01
Eritrea	2.94E-09	1.01E-08	5.31E-09	6.54E-04	2.18E-03	1.51E-03	6.68E+00	1.81E+01	1.76E+01
Estonia	5.29E-09	1.35E-08	8.06E-09	1.65E-03	5.70E-03	6.36E-03	9.83E+00	4.02E+01	3.52E+01
Ethiopia	3.05E-09	9.85E-09	5.22E-09	6.18E-04	1.85E-03	1.68E-03	7.94E+00	1.93E+01	2.31E+01
Faroe Isl.	3.34E-09	1.44E-08	8.02E-09	8.13E-04	1.91E-03	2.13E-03	4.74E+00	8.08E+00	9.95E+00
Falkland Isl.	4.02E-09	1.50E-08	7.78E-09	1.90E-04	2.89E-04	2.36E-03	1.45E+00	2.14E+00	1.49E+01
Fiji	3.77E-09	9.90E-09	5.09E-09	2.38E-05	4.32E-05	4.67E-05	1.70E-01	3.26E-01	6.80E-01

Country	$\sum FF$ (keq·kg^{-1})			$\sum FF \cdot SF$ (mol H·m^2·yr·kg^{-1})			$\sum FF \cdot SF \cdot EF$ (m^2·yr·kg^{-1})		
	NO_x	**NH_3**	**SO_2**	**NO_x**	**NH_3**	**SO_2**	**NO_x**	**NH_3**	**SO_2**
Finland	5.30E-09	1.29E-08	7.94E-09	1.58E-03	6.47E-03	9.09E-03	8.14E+00	2.30E+01	3.24E+01
France	4.69E-09	1.35E-08	7.34E-09	1.67E-03	9.13E-03	4.30E-03	9.96E+00	5.57E+01	2.71E+01
French Guiana	3.01E-09	9.82E-09	5.19E-09	3.71E-04	2.51E-03	1.44E-03	3.00E+00	1.91E+01	1.09E+01
French Polynesia	3.88E-09	9.79E-09	5.17E-09	1.53E-05	3.72E-06	6.29E-06	1.10E-01	2.87E-02	3. 60E-02
French Southern Antarctic Lands	3.61E-09	1.46E-08	7.59E-09	1.47E-04	6.12E-06	8.51E-05	1.07E+00	5.65E-02	7.50E-01
Gabon	2.25E-09	9.65E-09	5.12E-09	5.28E-04	4.35E-03	2.99E-03	5.24E+00	4.16E+01	3.50E+01
Gaza Strip	3.74E-09	1.06E-08	5.82E-09	1.76E-03	4.59E-03	3.35E-03	7.25E+00	2.15E+01	1.81E+01
Georgia	4.42E-09	1.16E-08	6.78E-09	1.86E-03	1.02E-02	5.14E-03	1.10E+01	5.73E+01	3.34E+01
Germany	4.99E-09	1.40E-08	7.68E-09	2.16E-03	1.25E-02	6.12E-03	1.07E+01	5.73E+01	2.96E+01
Ghana	3.14E-09	9.83E-09	5.25E-09	2.80E-04	1.41E-03	1.56E-03	2.85E+00	1.25E+01	1.87E+01
Greece	4.16E-09	1.18E-08	6.42E-09	1.06E-03	3.78E-03	1.97E-03	8.60E+00	3.28E+01	2.21E+01
Greenland	3.43E-09	1.36E-08	7.66E-09	2.76E-04	1.20E-03	2.95E-03	1.96E+00	1.95E+01	5.13E+01
Grenada	3.31E-09	1.01E-08	5.31E-09	2.39E-04	1.52E-03	5.02E-04	2.35E+00	1.21E+01	4.25E+00
Guadeloupe	2.40E-09	1.04E-08	5.46E-09	1.35E-04	1.47E-03	4.54E-04	1.13E+00	1.01E+01	3.57E+00
Guam	3.03E-09	9.88E-09	5.19E-09	1.14E-04	5.31E-04	2.77E-04	6.53E-01	3.13E+00	1.69E+00
Guatemala	3.24E-09	1.01E-08	5.28E-09	2.93E-04	2.39E-03	1.04E-03	2.71E+00	2.14E+01	6.66E+00
Guinea	3.05E-09	9.91E-09	5.24E-09	3.44E-04	2.70E-03	1.33E-03	0.00E+00	0.00E+00	0.00E+00
Guinea-Bissau	3.06E-09	9.96E-09	5.20E-09	3.10E-04	2.44E-03	9.14E-04	3.13E+00	2.75E+01	1.29E+01
Guyana	3.06E-09	9.79E-09	5.20E-09	6.12E-04	4.81E-03	2.07E-03	2.17E+00	1.49E+01	6.83E+00
Haiti	3.11E-09	1.04E-08	5.47E-09	1.89E-04	1.54E-03	4.61E-04	5.02E+00	3.69E+01	1.56E+01
Honduras	3.27E-09	1.00E-08	5.28E-09	2.58E-04	1.75E-03	8.30E-04	1.61E+00	1.21E+01	4.69E+00
Hungary	4.77E-09	1.32E-08	7.22E-09	1.97E-03	9.90E-03	4.62E-03	2.86E+00	2.15E+01	8.67E+00
Iceland	4.62E-09	1.54E-08	7.81E-09	4.76E-04	4.53E-03	2.77E-03	1.07E+01	5.25E+01	2.66E+01

Country	$\sum FF$ (keq·kg^{-1})			$\sum FF \cdot SF$ (mol H·m^2·yr·kg^{-1})			$\sum FF \cdot SF \cdot EF$ (m^2·yr·kg^{-1})		
	NO_x	NH_3	SO_2	NO_x	NH_3	SO_2	NO_x	NH_3	SO_2
India	3.49E-09	1.03E-08	5.50E-09	8.87E-04	2.11E-03	1.66E-03	3.04E+00	3.37E+01	2.12E+01
Indonesia	2.97E-09	9.61E-09	5.06E-09	3.41E-04	1.24E-03	1.14E-03	5.48E+00	1.30E+01	1.12E+01
Iran	3.80E-09	1.07E-08	5.99E-09	1.28E-03	4.12E-03	2.71E-03	2.07E+00	7.51E+00	6.22E+00
Iraq	3.86E-09	1.08E-08	6.09E-09	1.33E-03	3.07E-03	2.58E-03	7.31E+00	2.58E+01	1.86E+01
Ireland	4.66E-09	1.45E-08	7.79E-09	8.90E-04	3.23E-03	3.08E-03	7.33E+00	2.04E+01	1.70E+01
Isle of Man	4.81E-09	1.46E-08	7.93E-09	1.10E-03	5.20E-03	3.51E-03	5.04E+00	1.75E+01	1.71E+01
Israel	3.73E-09	1.06E-08	5.82E-09	2.39E-03	6.23E-03	4.74E-03	5.97E+00	2.80E+01	1.97E+01
Italy	4.49E-09	1.29E-08	6.50E-09	1.77E-03	1.20E-02	3.15E-03	7.55E+00	2.32E+01	1.95E+01
Jamaica	3.19E-09	1.03E-08	5.42E-09	2.06E-04	1.67E-03	4.95E-04	9.50E+00	4.79E+01	2.16E+01
Jan Mayen	4.21E-09	1.35E-08	7.79E-09	4.54E-04	5.28E-04	8.01E-04	1.65E+00	1.12E+01	4.64E+00
Japan	3.98E-09	9.86E-09	5.75E-09	7.30E-04	4.08E-03	2.06E-03	2.58E+00	2.54E+00	5.81E+00
Jersey	4.77E-09	1.40E-08	7.59E-09	1.28E-03	5.61E-03	3.24E-03	7.53E+00	3.17E+01	2.01E+01
Jordan	3.74E-09	1.06E-08	5.83E-09	1.60E-03	3.84E-03	4.01E-03	7.28E+00	2.26E+01	1.94E+01
Kazakhstan	4.76E-09	1.10E-08	7.05E-09	1.89E-03	5.88E-03	4.29E-03	1.38E+01	5.15E+01	3.95E+01
Kenya	3.11E-09	9.70E-09	5.13E-09	6.92E-04	2.47E-03	2.32E-03	8.85E+00	2.35E+01	3.00E+01
Kiribati	3.56E-09	9.57E-09	4.96E-09	2.49E-05	8.68E-06	2.89E-05	1.61E-01	6.77E-02	1.80E-01
Kuwait	3.65E-09	1.06E-08	5.75E-09	1.86E-03	5.12E-03	4.35E-03	6.96E+00	2.68E+01	1.37E+01
Kyrgyzstan	4.18E-09	1.02E-08	6.29E-09	3.37E-03	1.61E-02	7.15E-03	1.95E+01	1.07E+02	4.32E+01
Laos	3.24E-09	1.00E-08	5.44E-09	6.19E-04	1.75E-03	1.37E-03	5.19E+00	2.08E+01	1.33E+01
Latvia	5.23E-09	1.37E-08	7.97E-09	1.61E-03	6.00E-03	5.33E-03	1.02E+01	5.17E+01	3.50E+01
Lebanon	3.83E-09	1.08E-08	5.97E-09	1.17E-03	2.73E-03	1.79E-03	7.28E+00	2.30E+01	1.64E+01
Lesotho	3.50E-09	1.09E-08	5.78E-09	6.57E-04	1.39E-03	1.31E-03	3.48E+00	6.60E+00	8.78E+00
Liberia	2.72E-09	9.78E-09	5.20E-09	3.68E-04	5.99E-03	1.83E-03	2.94E+00	4.42E+01	1.64E+01

	$\sum FF$ (keq·kg^{-1})			$\sum FF \cdot SF$ (mol H·m^2·yr·kg^{-1})			$\sum FF \cdot SF \cdot EF$ (m^2·yr·kg^{-1})		
Country	**NO_x**	**NH_3**	**SO_2**	**NO_x**	**NH_3**	**SO_2**	**NO_x**	**NH_3**	**SO_2**
Libya	3.58E-09	1.07E-08	5.79E-09	6.49E-04	2.30E-03	1.46E-03	7.60E+00	2.34E+01	3.44E+01
Liechtenstein	4.80E-09	1.36E-08	7.36E-09	2.08E-03	1.19E-02	5.49E-03	1.08E+01	5.95E+01	2.93E+01
Lithuania	5.19E-09	1.37E-08	7.90E-09	1.67E-03	6.64E-03	5.32E-03	1.04E+01	5.18E+01	3.48E+01
Luxembourg	4.92E-09	1.39E-08	7.59E-09	2.08E-03	1.42E-02	6.13E-03	1.12E+01	7.80E+01	3.39E+01
Macedonia	4.35E-09	1.22E-08	6.68E-09	1.69E-03	8.27E-03	4.56E-03	1.03E+01	4.15E+01	2.77E+01
Madagascar	3.01E-09	1.00E-08	5.29E-09	5.39E-04	2.22E-03	1.54E-03	4.48E+00	1.65E+01	1.41E+01
Malawi	2.98E-09	9.82E-09	5.21E-09	8.35E-04	3.22E-03	3.39E-03	1.20E+01	4.19E+01	6.26E+01
Malaysia	3.08E-09	9.63E-09	5.13E-09	3.47E-04	8.80E-04	1.04E-03	2.14E+00	5.50E+00	5.89E+00
Mali	3.22E-09	1.01E-08	5.31E-09	4.52E-04	3.46E-03	1.67E-03	4.16E+00	3.51E+01	1.97E+01
Malta	3.81E-09	1.15E-08	6.25E-09	7.88E-04	2.63E-03	1.72E-03	6.28E+00	1.88E+01	1.59E+01
Martinique	2.54E-09	1.03E-08	5.38E-09	1.54E-04	1.48E-03	4.62E-04	1.38E+00	1.09E+01	3.75E+00
Mauritania	3.24E-09	1.02E-08	5.32E-09	8.25E-04	9.13E-03	2.84E-03	4.56E+00	3.87E+01	1.68E+01
Mauritius	3.31E-09	1.00E-08	5.27E-09	2.08E-04	4.80E-04	3.14E-04	1.86E+00	4.14E+00	3.62E+00
Mayotte	2.97E-09	9.79E-09	5.14E-09	3.62E-04	9.62E-04	8.44E-04	4.14E+00	9.54E+00	1.13E+01
Mexico	3.54E-09	1.07E-08	5.51E-09	5.15E-04	4.28E-03	1.86E-03	3.93E+00	3.20E+01	9.74E+00
Moldova	4.72E-09	1.29E-08	7.16E-09	1.28E-03	3.85E-03	2.98E-03	8.60E+00	2.84E+01	2.15E+01
Micronesia	3.02E-09	9.66E-09	5.03E-09	2.53E-05	1.10E-04	1.28E-04	1.53E-01	7.13E-01	8.59E-01
Mongolia	4.31E-09	7.80E-09	5.67E-09	1.68E-03	4.40E-03	4.52E-03	1.17E+01	4.69E+01	4.24E+01
Montserrat	2.40E-09	1.04E-08	5.46E-09	1.35E-04	1.47E-03	4.54E-04	1.13E+00	1.01E+01	3.57E+00
Morocco	3.78E-09	1.13E-08	6.01E-09	4.41E-04	2.01E-03	8.54E-04	7.43E+00	4.20E+01	1.93E+01
Mozambique	3.06E-09	9.98E-09	5.46E-09	6.23E-04	1.85E-03	2.45E-03	6.42E+00	1.71E+01	2.14E+01
Myanmar	3.41E-09	1.02E-08	5.56E-09	7.18E-04	2.15E-03	2.06E-03	4.96E+00	1.45E+01	1.49E+01
Namibia	3.10E-09	1.02E-08	5.40E-09	9.15E-04	4.22E-03	1.41E-03	4.95E+00	1.28E+01	1.55E+01

	$\sum FF$ (keq·kg^{-1})			$\sum FF \cdot SF$ (mol H·m^2·yr·kg^{-1})			$\sum FF \cdot SF \cdot EF$ (m^2·yr·kg^{-1})		
Country	**NO$_x$**	**NH$_3$**	**SO$_2$**	**NO$_x$**	**NH$_3$**	**SO$_2$**	**NO$_x$**	**NH$_3$**	**SO$_2$**
Nepal	3.60E-09	1.05E-08	5.56E-09	1.15E-03	3.45E-03	2.16E-03	8.37E+00	2.49E+01	1.84E+01
Netherland	5.02E-09	1.42E-08	7.82E-09	1.84E-03	1.02E-02	5.00E-03	8.74E+00	3.56E+01	1.98E+01
Netherlands Antilles	3.22E-09	1.00E-08	5.23E-09	2.27E-04	1.56E-03	4.30E-04	2.49E+00	1.68E+01	4.40E+00
New Caledonia	3.70E-09	1.01E-08	5.28E-09	4.28E-05	1.55E-04	2.41E-04	3.02E-01	1.11E+00	2.25E+00
New Zealand	4.02E-09	1.28E-08	5.98E-09	4.77E-04	1.77E-03	2.16E-03	3.22E+00	1.69E+01	1.13E+01
Nicaragua	3.19E-09	9.99E-09	5.20E-09	2.45E-04	1.66E-03	9.11E-04	2.48E+00	1.88E+01	7.34E+00
Niger	3.20E-09	1.02E-08	5.40E-09	5.72E-04	3.25E-03	5.04E-03	6.20E+00	2.47E+01	4.33E+01
Nigeria	3.10E-09	9.87E-09	5.19E-09	4.63E-04	1.82E-03	2.05E-03	5.28E+00	1.74E+01	2.03E+01
Niue	3.92E-09	1.00E-08	5.19E-09	2.21E-05	1.55E-05	1.76E-05	1.58E-01	1.01E-01	1.41E-01
North Korea	4.24E-09	9.71E-09	5.95E-09	1.94E-03	1.23E-02	4.18E-03	8.88E+00	4.70E+01	2.19E+01
Norway	5.24E-09	1.34E-08	7.96E-09	1.83E-03	1.39E-02	5.75E-03	7.47E+00	4.10E+01	2.18E+01
Oman	3.30E-09	1.03E-08	5.44E-09	8.27E-04	2.63E-03	1.70E-03	6.09E+00	1.95E+01	1.56E+01
Palau	2.10E-09	9.72E-09	5.16E-09	1.88E-04	5.68E-04	3.51E-04	1.06E+00	3.35E+00	2.24E+00
Pakistan	3.45E-09	1.05E-08	5.72E-09	2.37E-03	9.12E-03	6.27E-03	8.79E+00	3.08E+01	2.31E+01
Panama	3.16E-09	9.82E-09	5.15E-09	2.81E-04	2.16E-03	1.39E-03	2.30E+00	1.69E+01	7.48E+00
Papua New Guinea	2.62E-09	9.63E-09	5.05E-09	1.07E-04	5.57E-04	5.52E-04	7.52E-01	4.04E+00	4.20E+00
Paraguay	3.16E-09	1.04E-08	5.50E-09	3.81E-04	2.07E-03	2.48E-03	3.01E+00	1.72E+01	1.67E+01
Peru	3.22E-09	9.73E-09	5.21E-09	8.36E-04	6.49E-03	6.92E-03	3.39E+00	2.57E+01	1.51E+01
Philippines	2.98E-09	9.72E-09	5.27E-09	3.51E-04	1.00E-03	8.40E-04	2.16E+00	6.45E+00	5.41E+00
Pitcairn Isl.	4.12E-09	1.04E-08	5.54E-09	3.07E-05	1.50E-05	4.86E-05	2.18E-01	1.00E-01	2.16E-01
Poland	5.04E-09	1.38E-08	7.66E-09	2.27E-03	1.45E-02	6.55E-03	1.09E+01	5.63E+01	2.97E+01
Portugal	4.19E-09	1.23E-08	6.53E-09	8.81E-04	6.75E-03	2.23E-03	6.91E+00	4.45E+01	1.69E+01
Puerto Rico	3.20E-09	1.04E-08	5.48E-09	1.68E-04	1.47E-03	4.08E-04	1.40E+00	1.04E+01	3.79E+00

Country	$\sum FF$ (keq·kg^{-1})			$\sum FF \cdot SF$ (mol H·m^2·yr·kg^{-1})			$\sum FF \cdot SF \cdot EF$ (m^2·yr·kg^{-1})		
	NO_x	NH_3	SO_2	NO_x	NH_3	SO_2	NO_x	NH_3	SO_2
Qatar	3.48E-09	1.04E-08	5.54E-09	1.69E-03	5.10E-03	3.14E-03	6.36E+00	2.85E+01	1.57E+01
Reunion	3.28E-09	1.01E-08	5.34E-09	2.44E-04	5.58E-04	6.98E-04	2.14E+00	4.80E+00	9.15E+00
Romania	4.62E-09	1.28E-08	7.05E-09	1.67E-03	1.02E-02	4.62E-03	9.92E+00	4.93E+01	2.72E+01
Russia	5.12E-09	1.12E-08	7.72E-09	1.63E-03	6.40E-03	5.80E-03	1.24E+01	5.29E+01	4.77E+01
Rwanda	2.28E-09	9.66E-09	5.13E-09	5.91E-04	4.50E-03	4.07E-03	6.87E+00	3.69E+01	5.45E+01
Samoa	3.75E-09	9.80E-09	5.06E-09	1.81E-05	1.57E-05	2.12E-05	1.26E-01	1.07E-01	1.68E-01
Sao Tome & Principe	1.90E-09	9.65E-09	5.14E-09	1.59E-04	1.20E-03	1.75E-03	0.00E+00	1.11E+01	1.98E+01
Saudi Arabia	3.40E-09	1.04E-08	5.54E-09	2.10E-03	6.33E-03	6.89E-03	1.38E+00	2.85E+01	2.06E+01
Senegal	3.25E-09	1.01E-08	5.25E-09	4.72E-04	3.26E-03	1.95E-03	8.07E+00	1.52E+01	1.03E+01
Serbia & Montenegro	4.51E-09	1.26E-08	6.90E-09	1.77E-03	8.51E-03	4.68E-03	2.57E+00	4.82E+01	2.85E+01
Seychelles	3.06E-09	9.73E-09	5.11E-09	3.78E-04	8.11E-04	7.54E-04	1.06E+01	7.57E+00	9.57E+00
Sierra Leone	2.79E-09	9.84E-09	5.22E-09	3.93E-04	5.35E-03	1.81E-03	4.40E+00	5.05E+01	1.74E+01
Slovakia	4.88E-09	1.34E-08	7.44E-09	2.22E-03	1.38E-02	6.26E-03	3.59E+00	6.31E+01	2.99E+01
Slovenia	4.65E-09	1.31E-08	7.14E-09	2.16E-03	1.54E-02	5.71E-03	1.12E+01	6.61E+01	2.90E+01
Solomon Isl.	3.11E-09	9.66E-09	5.05E-09	2.33E-05	8.12E-05	1.69E-04	1.09E+01	6.11E-01	1.43E+00
Somalia	3.13E-09	9.79E-09	5.19E-09	6.64E-04	2.81E-03	1.24E-03	1.55E-01	2.32E+01	1.18E+01
South Africa	3.47E-09	1.08E-08	5.72E-09	7.46E-04	2.46E-03	1.60E-03	6.83E+00	1.12E+01	1.15E+01
South Georgia & the South Sandwich Isl.	3.71E-09	1.56E-08	8.37E-09	2.16E-04	8.53E-05	6.14E-05	4.42E+00	6.77E-01	6.04E-01
South Korea	3.95E-09	9.77E-09	5.84E-09	1.12E-03	4.19E-03	2.29E-03	1.76E+00	2.65E+01	1.53E+01
Spain	4.26E-09	1.24E-08	6.71E-09	1.02E-03	5.71E-03	2.76E-03	6.18E+00	5.65E+01	2.35E+01
Sri Lanka	3.10E-09	9.74E-09	5.16E-09	2.69E-04	4.94E-04	3.55E-04	9.27E+00	4.28E+00	2.98E+00
St. Helena	2.44E-09	9.84E-09	5.14E-09	2.02E-04	4.00E-04	2.29E-04	1.85E+00	3.41E+00	2.03E+00
St. Lucia	2.54E-09	1.03E-08	5.38E-09	1.54E-04	1.48E-03	4.62E-04	1.57E+00	1.09E+01	3.75E+00

Country	$\sum FF$ (keq·kg^{-1})			$\sum FF \cdot SF$ (mol H·m^2·yr·kg^{-1})			$\sum FF \cdot SF \cdot EF$ (m^2·yr·kg^{-1})		
	NO_x	NH_3	SO_2	NO_x	NH_3	SO_2	NO_x	NH_3	SO_2
St. Kitts & Nevis	3.22E-09	1.05E-08	5.51E-09	1.63E-04	1.47E-03	4.32E-04	1.38E+00	9.55E+00	3.34E+00
Sudan	3.09E-09	9.87E-09	5.23E-09	9.46E-04	3.46E-03	3.49E-03	1.32E+00	4.90E+01	6.02E+01
Suriname	2.97E-09	9.81E-09	5.20E-09	4.52E-04	3.34E-03	1.52E-03	1.53E+01	2.50E+01	1.13E+01
Svalbard	4.53E-09	1.05E-08	7.22E-09	6.53E-04	3.51E-04	3.77E-04	4.59E+00	1.78E+00	2.04E+00
Swaziland	3.44E-09	1.06E-08	5.64E-09	6.12E-04	1.30E-03	1.40E-03	4.62E+00	1.34E+01	1.35E+01
Sweden	5.24E-09	1.37E-08	7.98E-09	2.11E-03	1.98E-02	7.73E-03	9.02E+00	6.29E+01	2.85E+01
Switzerland	4.71E-09	1.34E-08	7.26E-09	2.09E-03	1.39E-02	5.56E-03	1.06E+01	5.73E+01	2.81E+01
Syria	3.99E-09	1.09E-08	6.14E-09	1.12E-03	2.59E-03	1.87E-03	7.25E+00	1.97E+01	1.59E+01
Tajikistan	4.03E-09	1.04E-08	6.20E-09	2.82E-03	8.94E-03	6.13E-03	1.64E+01	5.67E+01	4.08E+01
Tanzania	3.00E-09	9.70E-09	5.14E-09	6.05E-04	2.02E-03	2.61E-03	8.55E+00	2.33E+01	4.38E+01
Thailand	3.07E-09	1.00E-08	5.39E-09	5.21E-04	1.28E-03	1.13E-03	4.64E+00	1.93E+01	1.28E+01
Gambia	3.26E-09	1.01E-08	5.23E-09	3.63E-04	2.31E-03	1.75E-03	2.21E+00	1.45E+01	7.87E+00
East Timor	2.73E-09	9.68E-09	5.10E-09	1.69E-04	4.81E-04	4.50E-04	1.38E+00	5.35E+00	6.11E+00
Togo	3.15E-09	9.84E-09	5.26E-09	2.95E-04	1.31E-03	1.60E-03	3.14E+00	1.18E+01	1.93E+01
Tonga	3.93E-09	1.00E-08	5.17E-09	2.32E-05	3.00E-05	3.01E-05	1.66E-01	1.93E-01	2.52E-01
Trinidad Tobago	3.26E-09	9.98E-09	5.25E-09	3.03E-04	1.53E-03	5.91E-04	3.15E+00	1.36E+01	5.25E+00
Tunisia	3.74E-09	1.14E-08	6.21E-09	7.33E-04	2.30E-03	1.41E-03	7.28E+00	2.58E+01	2.40E+01
Turkey	4.18E-09	1.14E-08	6.40E-09	1.13E-03	3.64E-03	2.20E-03	8.75E+00	3.02E+01	2.12E+01
Turkmenistan	4.05E-09	1.06E-08	6.32E-09	2.14E-03	7.51E-03	4.84E-03	1.10E+01	3.83E+01	3.51E+01
Turks & Caicos Isl.	2.17E-09	1.07E-08	5.65E-09	2.02E-04	1.86E-03	5.59E-04	1.31E+00	1.06E+01	3.92E+00
Uganda	2.95E-09	9.69E-09	5.15E-09	8.31E-04	4.06E-03	3.97E-03	1.24E+01	5.80E+01	6.47E+01
Ukraine	4.89E-09	1.30E-08	7.36E-09	1.23E-03	4.36E-03	2.98E-03	8.71E+00	3.30E+01	2.26E+01
United Arab Emirates	3.37E-09	1.04E-08	5.47E-09	1.29E-03	5.28E-03	2.81E-03	7.25E+00	2.84E+01	2.33E+01

	$\sum FF$ (keq·kg^{-1})			$\sum FF \cdot SF$ (mol H·m^2·yr·kg^{-1})			$\sum FF \cdot SF \cdot EF$ (m^2·yr·kg^{-1})		
Country	**NO$_x$**	**NH$_3$**	**SO$_2$**	**NO$_x$**	**NH$_3$**	**SO$_2$**	**NO$_x$**	**NH$_3$**	**SO$_2$**
United Kingdom	4.88E-09	1.44E-08	7.86E-09	1.31E-03	6.96E-03	3.93E-03	7.14E+00	3.67E+01	2.19E+01
USA	4.20E-09	1.23E-08	6.45E-09	1.52E-03	1.35E-02	4.82E-03	8.16E+00	7.34E+01	2.52E+01
Uruguay	3.54E-09	1.13E-08	5.98E-09	2.65E-04	1.08E-03	9.96E-04	1.95E+00	7.75E+00	6.64E+00
Uzbekistan	4.16E-09	1.05E-08	6.29E-09	2.48E-03	6.86E-03	6.14E-03	1.45E+01	4.70E+01	4.30E+01
Vanuatu	3.64E-09	9.82E-09	4.96E-09	2.46E-05	7.16E-05	8.27E-05	1.72E-01	5.04E-01	6.99E-01
Venezuela	3.14E-09	9.82E-09	5.22E-09	3.86E-04	2.84E-03	8.10E-04	4.02E+00	2.94E+01	7.95E+00
Vietnam	3.23E-09	1.00E-08	5.45E-09	6.19E-04	1.74E-03	1.64E-03	4.75E+00	1.58E+01	1.30E+01
Virgin Isl.	3.22E-09	1.05E-08	5.51E-09	1.63E-04	1.47E-03	4.32E-04	1.32E+00	9.55E+00	3.34E+00
Wallis & Futuna	3.78E-09	9.78E-09	5.01E-09	1.95E-05	3.03E-05	3.48E-05	1.40E-01	2.07E-01	2.92E-01
West Bank	3.76E-09	1.06E-08	5.84E-09	1.47E-03	3.17E-03	2.93E-03	7.35E+00	2.33E+01	1.89E+01
Western Sahara	3.25E-09	1.08E-08	5.58E-09	3.52E-04	2.02E-03	1.01E-03	4.65E+00	5.56E+01	1.58E+01
Yemen	3.10E-09	1.01E-08	5.29E-09	7.92E-04	3.17E-03	1.85E-03	6.22E+00	2.15E+01	1.59E+01
Zambia	3.02E-09	9.83E-09	5.22E-09	7.51E-04	2.30E-03	5.30E-03	1.17E+01	3.60E+01	1.06E+02
Zimbabwe	3.08E-09	1.01E-08	5.40E-09	6.76E-04	1.66E-03	2.64E-03	5.88E+00	1.27E+01	2.71E+01

Appendix S3.3 Importance of transboundary emissions

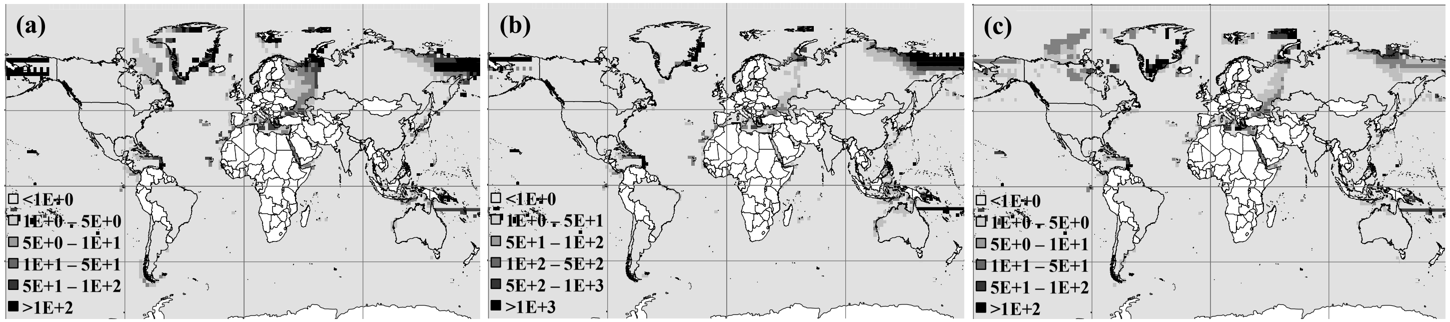

Figure S3.3.1 *Percentage of transcontinental potential impacts of* ***(a)*** *NO_x,* ***(b)*** *NH_3 and* ***(c)*** *SO_2 continental emissions*

Appendix S4.1

Appendix S4.1 CO_2 partial pressure to marine water pH conversion

When CO_2 partial pressure (pCO_2) for ocean water was reported instead of pH, we employed the following conversion equation (Figure S4.1.1) based on pCO_2 and pH data reported by Feely *et al.* (2009).

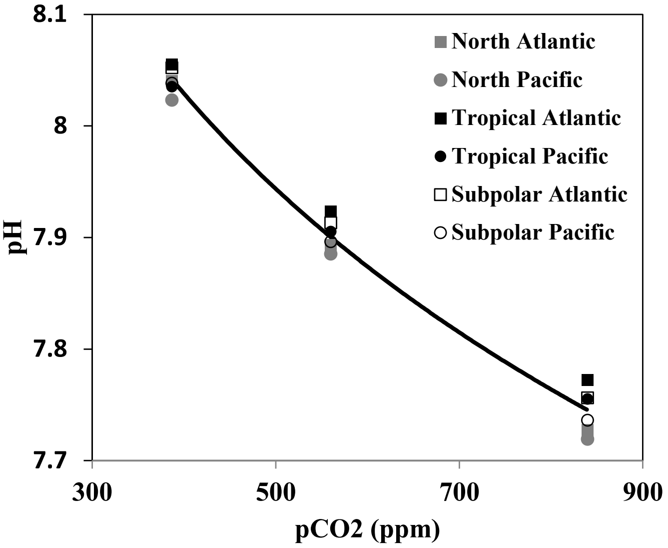

Figure S4.1.1 *Correlation between pCO_2 and pH, based on the work of Feely et al. (2009) for different world's oceans. The equation for pCO_2 transformation to pH are $-0.38^{(\text{Standard error} = 0.01)} \cdot \ln(pCO_2) + 10.32^{(\text{Standard error} = 0.07)}$ (p value < 0.001, $R^2 = 0.99$).*

Appendix S4.2 Abbreviation of species names

***Table S4.2.1** Abbreviation of species names.*

Abreviation	**Species name**
Aca_ery	*Acartia erythraea*
Aca_ste	*Acartia steueri*
Acr_eur	*Acropora eurystoma*
Acr_int	*Acropora intermedia*
Amp_fil	*Amphiura filiformis*
Arb_pun	*Arbacia punctulata*
Arg_irr	*Argopecten irradians*
Cal_lep	*Calcidiscus leptoporus*
Cal_sap	*Callinectes sapidus*
Cra_gig	*Crassostrea gigas*
Cra_vir	*Crassostrea virginica*
Cre_for	*Crepidula fornicata*
Ech_mat	*Echinometra mathaei*
Emi_hux	*Emiliania huxleyi*
Euc_tri	*Eucidaris tribuloides*
Eve_chl	*Evechinus chloroticus*
Fav_fra	*Favia fragum*
Gam_loc	*Gammarus locusta*
Gep_oce	*Gephyrocapsa oceanica*
Hal_inc	*Halimeda incrassata*
Hel_ery	*Heliocidaris erythrogramma*
Hem_pul	*Hemicentrotus pulcherrimus*
Hom_ame	*Homarus americanus*
Lit_lit	*Littorina littorea*
Lop_per	*Lophelia pertusa*
Mer_mer	*Mercenaria mercenaria*
Mya_are	*Mya arenaria*
Myt_edi	*Mytilus edulis*
Ocu_arb	*Oculina arbuscula*
Oph_fra	*Ophiothrix fragilis*
Osi_tur	*Osilinus turbinata*
Pen_ple	*Penaeus plebejus*
Por_ast	*Porites astreoides*
Por_com	*Porites compressa*
Por_lob	*Porites lobata*
Por_lut	*Porites lutea*
Por_onk	*Porolithon onkodes*
Pse_hut	*Pseudechinus huttoni*
Sac_glo	*Saccostrea glomerata*
Sem_bal	*Semibalanus balanoides*
Ste_neu	*Sterechinus neumayeri*
Str_ala	*Strombus alatus*
Sty_pis	*Stylophora pistillata*
Tri_gra	*Tripneustes gratilla*
Uro_cin	*Urosalpinx cinerea*

Appendix S4.3

Appendix S4.3 Selection of experimental data: literature review

Beneficial and uncertain effects of pH decrease on growth and reproduction and on growth, reproduction, and mortality are shown in Tables S4.3.1 and S4.3.2, respectively. List of studies comprising our literature review are shown in Table S4.3.3.

Table S4.3.1 *Logistic regression coefficients, i.e. EC$_{50}$ and slope β (95% confidence interval) for benefiting effects of pH decreases on species* ***(a)*** *growth and* ***(b)*** *reproduction.*

Species$^{\#,¶}$	**EC$_{50}$**	**β**	**R^2 / p value**
(a) Growth			
Pen_ple^{A}	7.73 (7.73 to 7.73)	0.12 (0.11 to 0.13)	1.00 / <0.001
Emi_hux^{H}	8.07 (8.06 to 8.07)	0.0008 (0.0007 to 0.0009)	1.00 / <0.001
(b) Reproduction			
Hem_pul^{E}	7.24 (6.99 to 7.49)	0.64 (0.36 to 2.78)	0.9 / <0.001
Ech_mat^{E}	7.69 (7.68 to 7.71)	0.09 (0.05 to 0.32)	1.00 / <0.001

$^{\#}$ Legend of abreviations of species names can be found in Table S4.2.1.
^{A}Arthropoda, ^{H}Haptophyta, ^{E}Echinodermata

Table S4.3.2 *Species for which logistic regression did not yield significant results (p value > 0.05) or that yielded slope β coefficient non-significantly different than zero. For these experiments, effects of pH decreases on species* ***(a)*** *growth,* ***(b)*** *reproduction, and* ***(c)*** *mortality are considered uncertain.*

Species$^{\#}$
(a) Growth
Arc_eur^{C}, Arc_int^{C}, Amp_fil^{E}, Arb_pun^{E}, Arg_irr^{M}, Cal_lep^{H}, Cal_sap^{A}, Cra_vir^{M}, Cre_for^{M}, Emi_hux^{H}, Euc_tri^{E}, Fav_fra^{C}, Gam_loc^{A}, Gep_oce^{H}, Hal_inc^{C}, Hom_ame^{A}, Lit_lit^{M}, Lop_per^{C}, Mer_mer^{M}, Mya_are^{M}, Myt_edi^{M}, Oph_fra^{E}, Por_ast^{C}, Por_com^{C}, Por_lob^{C}, Por_lut^{C}, Por_onk^{R}, Sac_glo^{M}, Sem_bal^{A}, Str_ala^{M}, Sty_pis^{C}, Uro_cin^{M}
(b) Reproduction
Aca_ery^{A}, Amp_fil^{E}, Ech_mat^{E}, Emi_hux^{H}, Hel_ery^{E}, Hem_pul^{E}, Oph_fra^{E}, Osi_tur^{M}, Sac_glo^{M}
(c) Mortality
Aca_ery^{A}, Aca_ste^{A}, Arg_irr^{M}, Eve_chl^{E}, Gam_loc^{A}, Mer_mer^{M}, Myt_edi^{M}, Pse_hut^{E}, Sem_bal^{A}, Ste_neu^{E}

$^{\#}$ Legend of abreviations of species names can be found in Table S4.2.1.
^{A}Arthropoda, ^{H}Haptophyta, ^{M}Mollusca, ^{E}Echinodermata, ^{C}Cnidaria

Table S4.3.3 *List of studies used in the study, the number of species and of experiments, and the experimental pH range for the specific phylum and response category.*

Study	Phylum	Response	Species	pH range
Albright *et al.* (2008)	C	G	1	7.80 – 7.99
Anthony *et al.* (2008)	C	G	2	7.65 – 8.20
Anthony *et al.* (2008)	R	G	1	7.65 – 8.20
Berge *et al.* (2006)	M	G	1	6.70 – 8.10
Berge *et al.* (2006)	M	S	1	6.70 – 8.10
Byrne *et al.* (2009)	E	R	1	7.67 – 8.20
Byrne *et al.* (2010)	E	R	1	7.60 – 8.17
Clark *et al.* (2009)	E	S	4	6.00 – 8.15
Cohen *et al.* (2009)	C	G	1	7.62 – 8.25
Dupont *et al.* (2008)	E	G	1	7.70 – 8.10
Dupont *et al.* (2008)	E	S	1	7.70 – 8.10
Dupont *et al.* (2008)	E	R	1	7.70 – 8.10
Findlay *et al.* (2010)	A	G	1	7.30 – 8.10
Findlay *et al.* (2010)	A	S	1	7.30 – 8.10
Gattuso *et al.* (1998)	C	G	2	7.34 – 8.30
Gazeau *et al.* (2007)	M	G	2	7.46 – 8.13
Hall-Spencer *et al.* (2008)	M	R	1	6.57 – 8.15
Hauton *et al.* (2009)	A	G	1	7.60 – 8.10
Hauton *et al.* (2009)	A	S	1	7.60 – 8.10
Kurihara & Shirayama (2004)	E	G	1	7.02 – 7.98
Kurihara & Shirayama (2004)	E	R	2	6.78 – 8.11
Kurihara *et al.* (2004a)	A	S	2	6.82 – 8.15
Kurihara *et al.* (2004a)	A	R	2	6.82 – 8.15
Kurihara *et al.* (2004b)	A	S	1	6.93 – 8.15
Kurihara *et al.* (2004b)	A	R	1	6.93 – 8.15
Kurihara *et al.* (2004b)	E	G	2	6.78 – 8.11
Kurihara *et al.* (2004b)	E	R	2	6.78 – 8.11
Shirayama & Kurihara (2004)	E	G	1	7.02 – 8.11
Shirayama & Kurihara (2004)	E	R	2	6.78 – 8.11
Kurihara (2008)[#]	E	R	2	6.78 – 8.11
Langer *et al.* (2006)	H	G	1	7.86 – 8.74
Langer *et al.* (2006)	H	S	1	7.86 – 8.74
Maier et a. (2009)	C	G	1	7.76 – 8.10
Marubini *et al.* (2001)	C	G	1	7.82 – 8.31
Marubini *et al.* (2001)	C	G	1	7.58 – 8.19

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Ohde & Hossain (2004)	C	G	1	7.65 – 8.46
Parker *et al.* (2009)	M	G	1	7.69 – 8.07
Parker *et al.* (2009)	M	R	1	7.69 – 8.07
Riebesell *et al.* (2000)	H	G	1	7.81 – 8.43
Riebesell *et al.* (2000)	A	G	3	7.31 – 8.03
Riebesell *et al.* (2000)	Ch	G	1	7.49 – 8.19
Riebesell *et al.* (2000)	C	G	1	7.48 – 8.11
Riebesell *et al.* (2000)	E	G	2	7.36 – 8.04
Riebesell *et al.* (2000)	M	G	9	7.42 – 8.15
Riebesell *et al.* (2000)	R	G	1	7.49 – 8.19
Schneider & Erez (2006)	C	G	1	7.87 – 8.50
Talmage & Gobler (2009)	M	G	3	7.48 – 8.08
Talmage & Gobler (2009)	M	S	3	7.48 – 8.08
Wood *et al.* (2008)	E	G	1	6.80 – 8.00
Wood *et al.* (2008)	E	R	1	6.80 – 8.00
Shipe & Brzezinski (2001)	H	G	1	7.92 – 8.56

Supporting information

Appendix S5.1 Keyword combination used in the Web of Science (Box 1) and list of peer-reviewed articles used in this study (Table S5.1.1)

The keyword combination (Box 1) resulted in approximately 6800 articles in June 2011. Later, we selected the articles that fulfilled our selection criteria, which consisted of:

(a) The organisms had to be reported at the species taxonomic level. Occasional infra specific records were also included (total of eighteen organisms reported at the variety or subspecies taxonomic level).

(b) Nutrients had to be reported as total P. Records of concentration which did not specified a value were not included, e.g. trophic state or below or above a given concentration.

(c) Studies focusing on other inland waters were excluded, i.e. brackish or inland saline, fish ponds, wastewater treatment plants, or (constructed) wetlands.

(d) The location of the study and the type of freshwater (stream or lake) had to be reported. We also included paleolimnology studies of diatoms if it was possible to relate the occurrence of species with TP concentrations.

(e) Reservoirs and ponds were considered as lakes while rivers and springs were considered as streams.

(f) If multiple sampling dates or locations were reported within a study, we only included records where there was a connection in the location and sampling time between species occurrence and total P concentrations.

BOX 1

1#: TS = ((freshwater* OR river* OR lake* OR stream* OR fresh-water* OR wetland* OR basin* OR floodplain* OR watershed* OR lagoon* OR creek*) AND (mesocosm* OR macrocosm* OR field* OR survey* OR landscape* OR site* OR habitat* OR ecosystem* OR gradient* OR region*) AND (phosph* OR orthop* OR ortho-P* OR nitrogen OR ammonium OR ammonia OR nitrate* OR eutroph* OR oligotroph* OR mesotroph* OR hypertroph* OR (trophi AND (level* OR stat*)) OR autoanalyzer OR (core SAME[1] sampl*) OR (dip SAME[1] net)))
#2: TS = (((EPT OR Ephemeroptera OR mayfly* OR Plecoptera OR stonefly* OR Trichoptera OR caddisfl* OR fish* OR insect* OR microfauna* OR fauna OR Animal* OR Annelid* OR Arthropod* OR Chordat* OR Cnidar* OR Mollusc* OR Nemat* OR Platyhelminth* OR Porifer* OR Rotifer*) SAME[1] (divers* OR species OR taxa OR taxon OR population* OR communit* OR abundance OR occur* OR compos* OR count* OR biodivers* OR biomass OR frequen* OR densit* OR assembl*)) AND #1)
#3: TS = (((macro-invertebrate* OR benthic OR (macro AND invertebrate*) OR macroinvertebrate* OR invertebrate* OR zooplankt* OR fauna OR autotroph* OR plankton* OR phyt* OR plant* OR chlorophyl* OR macrophyte OR (primar* SAME[1] product*) OR algae* OR flora OR diatom* OR photosynthe*) SAME[1] (divers* OR species OR taxa OR taxon OR population* OR communit* OR abundance OR occur* OR compos* OR count* OR biodivers* OR biomass OR frequen* OR densit* OR assembl*)) AND #1)
#4: TS = (((Plant* OR Bryoph* OR Chloroph* OR Cyanidioph* OR Glaucoph* OR Magnolioph* OR Pteridoph* OR Rhodoph*) SAME[1] (divers* OR species OR taxa OR taxon OR population* OR communit* OR abundance OR occur* OR compos* OR count* OR biodivers* OR biomass OR frequen* OR densit* OR assembl*)) AND #1)

Final harvest: #2 OR #3 OR #4

[1] SAME: Boolean keyword that selects two or more words within the same sentence

Appendix S5.1

Table S5.1.1 *Freshwater type, trophic group, and minimum and maximum total phosphorus (TP) concentration range within each study.*

Study	**Freshwater type**	**Trophic group**	**Range (mg P·L^{-1})**
Armstrong *et al.* (2003)	Lake	Autotroph	0.013 to 0.06
Ask *et al.* (2009)	Lake	Heterotroph	0.006 to 0.023
Bagella *et al.* (2010)	Lake	Auto/heterotroph	0.052 to 0.181
Beklioglu & Tan (2008)	Lake	Heterotroph	0.085 to 0.615
Bennion *et al.* (2000)	Lake	Autotroph	0.025 to 0.028
Bennion *et al.* (1995)	Lake	Autotroph	0.009 to 0.034
Bere & Tundisi (2011)	Stream	Autotroph	0 to 5.088
Bere & Tundisi (2010)	Stream	Auto/heterotroph	0.01 to 2.97
Bertolo *et al.* (2005)	Lake	Heterotroph	0.004 to 0.016
Bouvy *et al.* (2003)	Lake	Autotroph	0.005 to 0.18
Caballero *et al.* (2006)	Lake	Autotroph	0.652 to 7.1
Cabecinha *et al.* (2009a)	Lake	Autotroph	0.043 to 16.576
Cabecinha *et al.* (2009b)	Lake	Autotroph	0.018 to 8.236
Cai *et al.* (2011)	Lake	Heterotroph	0.06 to 0.17
Cantonati & Spitale (2009)	Stream	Autotroph	0.002 to 0.021
Capers *et al.* (2009)	Lake	Autotroph	0.027 to 0.045
Caputo *et al.* (2008)	Lake	Autotroph	0.006 to 3.187
Carol *et al.* (2006)	Lake	Heterotroph	0.012 to 0.375
Casas *et al.* (2011)	Lake/stream	Heterotroph	0.01 to 0.041
Casco *et al.* (2009)	Lake	Auto/heterotroph	0.011 to 0.115
Castro *et al.* (2007)	Lake	Heterotroph	0.08 to 0.3
Catalano *et al.* (2010)	Lake	Heterotroph	0.04 to 0.141
Čerba *et al.* (2010)	Lake	Heterotroph	0.01 to 1.16
Chellappa *et al.* (2008)	Lake	Autotroph	0.64 to 0.85
Chen *et al.* (2008)	Lake	Autotroph	0.005 to 0.098
Cheng *et al.* (2010)	Lake	Heterotroph	0.005 to 0.268
Coops *et al.* (2008)	Lake	Auto/heterotroph	0.04 to 0.21
Cottenie *et al.* (2001)	Lake	Heterotroph	0.221 to 0.506
Cowell *et al.* (2004)	Stream	Heterotroph	0.389 to 1.225
Cronin *et al.* (2006)	Lake	Heterotroph	0.003 to 0.008
Da Silva *et al.* (2005)	Lake	Autotroph	0.003 to 0.014
Dasí *et al.* (1998)	Lake	Autotroph	0.025 to 15.386
De Backer *et al.* (2010)	Lake	Auto/heterotroph	0.041 to 0.578
De Paggi & Devercelli (2011)	Stream	Heterotroph	0.072 to 4.329
Del Pozo *et al.* (2010)	Lake	Autotroph	0.051 to 5.913

Study	Freshwater type	Trophic group	Range (mg P·L^{-1})
DeNicola *et al.* (2004)	Lake	Autotroph	0.005 to 0.079
Devlin & Finkelstein (2011)	Lake	Autotroph	0.002 to 0.013
Dong *et al.* (2008)	Lake	Autotroph	0.051 to 0.258
Douda (2010)	Stream	Heterotroph	0.07 to 0.45
Dunn *et al.* (2008)	Stream	Auto/heterotroph	0.052 to 0.199
Edlund *et al.* (2009)	Lake	Autotroph	0.04 to 0.063
Ekdahl *et al.* (2007)	Lake	Autotroph	0.002 to 0.027
Epners *et al.* (2010)	Lake	Heterotroph	0.019 to 0.248
Erős *et al.* (2009)	Lake	Heterotroph	0.011 to 0.064
Fabris *et al.* (2009)	Stream	Autotroph	0.002 to 0.004
Feuchtmayr *et al.* (2009)	Lake	Autotroph	0.352 to 0.352
Free *et al.* (2009)	Lake	Autotroph	0.002 to 0.06
Friberg *et al.* (2009)	Stream	Heterotroph	0.01 to 0.044
Frost *et al.* (2003)	Lake	Heterotroph	0.004 to 0.176
Füreder *et al.* (2006)	Lake	Heterotroph	2.87 to 3.74
Gacia *et al.* (1994)	Lake	Autotroph	0.002 to 0.29
Gélinas & Pinel-Alloul (2008)	Lake	Heterotroph	0.004 to 0.023
Gregory-Eaves *et al.* (2003)	Lake	Autotroph	0.006 to 0.012
Güecker *et al.* (2011)	Stream	Heterotroph	0.104 to 0.666
Ha *et al.* (2002)	Stream	Autotroph	0.059 to 0.803
Ha *et al.* (1998)	Stream	Autotroph	0.062 to 0.441
Haberman *et al.* (2010)	Lake	Auto/heterotroph	0.021 to 0.22
Hadley *et al.* (2010)	Lake	Autotroph	0.027 to 0.027
Hausmann & Pienitz (2007)	Lake	Autotroph	0.001 to 0.01
Hausmann & Pienitz (2009)	Lake	Autotroph	0.005 to 0.029
Havens *et al.* (1996)	Lake	Auto/heterotroph	0.03 to 0.22
Hazewinkel *et al.* (2008)	Lake	Autotroph	5.22 to 41.97
Hessen & Leu (2006)	Lake	Autotroph	0.004 to 0.076
Hill *et al.* (2010)	Stream	Heterotroph	0.02 to 0.4
Hilt *et al.* (2010)	Lake	Autotroph	0.01 to 0.05
Holz *et al.* (1997)	Lake	Autotroph	0.1 to 0.38
Hough & Thompson (1996)	Lake	Autotroph	0.015 to 0.026
Hsieh *et al.* (2010)	Lake	Autotroph	0.006 to 0.011
Iglesias *et al.* (2011)	Lake	Heterotroph	0.024 to 2.4
Izaguirre *et al.* (1993)	Lake	Autotroph	0.027 to 0.404
Jansson *et al.* (2010)	Lake	Heterotroph	0.004 to 0.01
Jeppesen *et al.* (1998)	Lake	Heterotroph	0.4 to 1

Appendix S5.1

Study	Freshwater type	Trophic group	Range (mg P·L^{-1})
Jocqué *et al.* (2007)	Lake	Heterotroph	0.385 to 4.124
Joniak *et al.* (2007)	Lake	Autotroph	0.017 to 0.265
Jyväsjärvi *et al.* (2009)	Lake	Heterotroph	0.002 to 0.03
Karst-Riddoch *et al.* (2009)	Lake	Autotroph	0.003 to 0.074
Kirilova *et al.* (2008)	Lake	Autotroph	0.02 to 0.14
(2010)	Lake	Auto/heterotroph	0.03 to 0.3
Kirkwood *et al.* (2007)	Stream	Autotroph	0 to 0.664
Korosi *et al.* (2008)	Lake	Heterotroph	0.005 to 0.018
Köster & Pienitz (2006)	Lake	Autotroph	0.002 to 0.03
Kuczyńska-Kippen (2009)	Lake	Auto/heterotroph	0.08 to 0.76
Kuczyńska-Kippen & Joniak (2010a)	Lake	Heterotroph	0 to 0.76
Kuczyńska-Kippen & Joniak (2010b)	Lake	Auto/heterotroph	0.028 to 1.743
Lauridsen *et al.* (2008)	Lake	Heterotroph	0.093 to 0.101
Leitão & Léglize (2000)	Lake	Autotroph	0.04 to 0.212
Leland & Porter (2000)	Stream	Autotroph	0.043 to 1.534
Lenat & Crawford (1994)	Stream	Heterotroph	0.09 to 0.27
Lewin (2006)	Stream	Autotroph	0.46 to 0.6
Lewin & Smoliński (2006)	Lake	Autotroph	0.01 to 0.98
Liu & Wang (2007)	Lake	Heterotroph	0.176 to 0.344
Liu *et al.* (2009a)	Lake	Heterotroph	0.017 to 0.017
Liu *et al.* (2009b)	Lake	Autotroph	0.156 to 0.156
Lucca *et al.* (2010)	Lake	Heterotroph	0.005 to 0.012
Lund *et al.* (2010)	Lake	Heterotroph	0.037 to 0.28
Mäemets *et al.* (2010)	Lake	Autotroph	0.027 to 0.098
Magbanua *et al.* (2010)	Stream	Heterotroph	0.045 to 1.163
Mäkelä *et al.* (2004)	Lake	Autotroph	0.011 to 0.051
May (1995)	Lake	Heterotroph	0.002 to 0.277
May & O’Hare (2005)	Lake	Heterotroph	0.005 to 0.017
McGarrigle & Champ (1999)	Lake	Heterotroph	0.008 to 0.044
McIntire *et al.* (2007)	Lake	Autotroph	0.023 to 0.029
Meerhoff *et al.* (2003)	Lake	Heterotroph	0.159 to 0.242
Mehner *et al.* (2007)	Lake	Heterotroph	0.007 to 0.608
Mehner *et al.* (2005)	Lake	Heterotroph	0.013 to 0.268
Mieczan (2010)	Lake	Heterotroph	0.027 to 0.36
Miserendino (2009)	Stream	Heterotroph	0.01 to 0.09
Miserendino (2006)	Stream	Heterotroph	0.007 to 0.126
Miserendino & Archangenlsky (2006)	Stream	Heterotroph	0.007 to 0.126

Study	Freshwater type	Trophic group	Range (mg P·L^{-1})
Miserendino & Brand (2007)	Stream	Heterotroph	0.007 to 0.126
Moser *et al.* (2000)	Lake	Autotroph	0.005 to 0.03
Moss *et al.* (2005)	Lake	Auto/heterotroph	0.038 to 0.397
Naselli-Flores & Barone (1998)	Lake	Autotroph	0.025 to 0.11
Nedbalová *et al.* (2006)	Lake	Auto/heterotroph	0.002 to 0.011
Newall & Walsh (2005)	Stream	Autotroph	0.02 to 0.33
Nixdorf & Deneke (1997)	Lake	Autotroph	0.05 to 0.124
Nixdorf *et al.* (2003)	Lake	Autotroph	0.057 to 0.057
Nyström *et al.* (2006)	Lake	Heterotroph	0.006 to 0.056
Olin *et al.* (2010)	Lake	Heterotroph	0.007 to 0.055
Olin *et al.* (2002)	Lake	Heterotroph	0.012 to 0.13
Olrik (1998)	Lake	Autotroph	0.115 to 0.407
Özkan *et al.* (2010)	Lake	Auto/heterotroph	0.027 to 0.06
Pacheco *et al.* (2010)	Lake	Autotroph	0.022 to 0.147
Perbiche-Neves *et al.* (2011)	Stream	Autotroph	0 to 0.09
Pereira *et al.* (2002)	Lake	Heterotroph	0 to 1.2
Peretyatko *et al.* (2009)	Lake	Autotroph	0.051 to 0.599
Persson *et al.* (2004)	Lake	Heterotroph	0.002 to 0.01
Pla *et al.* (2005)	Lake	Autotroph	0.007 to 0.025
Ponader *et al.* (2007)	Stream	Autotroph	0.021 to 2.625
Post *et al.* (2008)	Lake	Heterotroph	0.008 to 0.047
Prchalová *et al.* (2008)	Lake	Heterotroph	0.018 to 0.032
Quinlan & Smol (2010)	Lake	Heterotroph	0.003 to 0.029
Rajagopal *et al.* (2010)	Lake	Autotroph	8 to 35
Reid (2005)	Lake	Autotroph	0.002 to 0.101
Romo *et al.* (2007)	Lake	Autotroph	0.017 to 0.022
Rosso *et al.* (2010)	Lake	Heterotroph	0.89 to 1.14
Rydin *et al.* (2008)	Lake	Heterotroph	0.002 to 0.007
Sager & Lachavanne (2009)	Lake	Autotroph	0.003 to 0.076
Sass *et al.* (2010)	Lake	Autotroph	0 to 0.094
Sayer *et al.* (2010)	Lake	Heterotroph	0.097 to 0.536
Schagerl *et al.* (2010)	Lake	Autotroph	0.006 to 0.298
Schlegel *et al.* (1998)	Lake	Autotroph	0.061 to 0.243
Schultz *et al.* (2006)	Lake	Heterotroph	0.07 to 0.95
Serieyssol *et al.* (2009)	Lake	Autotroph	0.013 to 0.017
Shao *et al.* (2001)	Lake	Heterotroph	0.214 to 0.794
Shinneman *et al.* (2009a)	Lake	Autotroph	0.011 to 0.145

Appendix S5.1

Study	Freshwater type	Trophic group	Range (mg P·L^{-1})
Shinneman *et al.* (2009b)	Lake	Autotroph	0.009 to 1.18
Skov *et al.* (2010)	Lake	Heterotroph	0.001 to 0.001
Smiley *et al.* (2009)	Stream	Heterotroph	0.042 to 2.894
Smith *et al.* (2007)	Stream	Heterotroph	0.012 to 0.556
Song *et al.* (2010)	Lake	Autotroph	0.086 to 0.377
Sosnovsky & Quirós (2009)	Lake	Heterotroph	0.923 to 4.07
Srivastava *et al.* (1995)	Lake	Autotroph	0.003 to 5.95
St. Jacques *et al.* (2005)	Lake	Auto/heterotroph	0.002 to 0.028
Steinman *et al.* (2011)	Lake	Autotroph	0.01 to 0.01
Stephen *et al.* (2004)	Lake	Auto/heterotroph	0.1 to 1.045
Stowa (2010)	Lake/stream	Heterotroph	0.01 to 17
Suutari *et al.* (2009)	Lake	Autotroph	0.023 to 0.277
Tarkowska-Kukuryk (2011)	Lake	Auto/heterotroph	0.049 to 0.37
Tate & Heiny (1995)	Stream	Heterotroph	0.019 to 4.722
Tátrai *et al.* (2008)	Lake	Heterotroph	0.035 to 0.067
Thiébaut (2006)	Stream	Autotroph	0.013 to 0.886
Tolotti *et al.* (2006)	Lake	Auto/heterotroph	0.003 to 0.01
Tonn *et al.* (2004)	Lake	Heterotroph	0.01 to 0.244
Tracy *et al.* (2003)	Lake	Autotroph	0.017 to 0.02
Train & Rodrigues (1998)	Stream	Autotroph	0.017 to 0.062
Trevisan *et al.* (2010)	Lake	Autotroph	0.006 to 0.03
Trigal *et al.* (2009)	Lake	Auto/heterotroph	0.063 to 2.088
Unrein *et al.* (2010)	Lake	Autotroph	0.235 to 1.6
Vakkilainen *et al.* (2004)	Lake	Heterotroph	0.047 to 1.511
Van Geest *et al.* (2007)	Lake	Heterotroph	0.002 to 0.062
Vázquez *et al.* (2011)	Stream	Autotroph	0.012 to 0.213
Vermonden *et al.* (2009)	Stream	Heterotroph	0.016 to 0.151
Vidaković & Bogut (2004)	Lake	Heterotroph	0.11 to 1.02
Villena & Romo (2007)	Lake	Autotroph	0.017 to 0.017
Vinocur & Pizarro (2000)	Lake	Auto/heterotroph	0.002 to 3.155
Vis *et al.* (2008)	Stream	Autotroph	0.025 to 0.048
Wærvågen & Nilssen (2010)	Lake	Heterotroph	0.008 to 0.008
Wang *et al.* (2007)	Lake	Heterotroph	0.002 to 0.024
Wen *et al.* (2011)	Lake	Heterotroph	0.015 to 0.105
Wu & Kow (2010)	Lake	Autotroph	0.005 to 0.08
Wunsam *et al.* (1995)	Lake	Autotroph	0.002 to 0.266
Xu *et al.* (2005)	Lake	Autotroph	0.054 to 0.565

Study	Freshwater type	Trophic group	Range (mg P·L^{-1})
Yang *et al.* (2006)	Lake	Autotroph	0.04 to 0.175
Ye *et al.* (2007)	Lake	Autotroph	0.014 to 0.188
Zambrano *et al.* (2006)	Lake	Heterotroph	0.031 to 0.49

Appendix S5.2

Appendix S5.2.2 Taxonomic classification tools, number of species and list of species within each trophic group.

We used the three taxonomic classification sources (ITIS, AlgaeBase, and PlantList, accessed in January, 2012) not only to classify the species into a species group but also to identify possible taxonomic synonyms (Table S5.2.1). Also, we revisited the studies reporting species which were not found in their respective taxonomic classification source to ensure that their names were not misprinted during the data gathering. However, if the species name was correct in their study and absent in the taxonomic classification source, we kept the species name in the dataset based on the rationale that the peer-reviewed source is more likely to contain a record than a taxonomic database. Also, we included occasional organisms that were reported in a variety or subspecies taxonomic level (total of eighteen) and considered these as another species-level record. The number of species in each species group can be found in Table 2.2. The fraction of species which were found exclusively below, above, and both below and above their respective C_{opt} is shown in Table 5.2.3. Finally, general scatter plots of species richness – TP concentration across regions are shown in Figure S5.2.1.

Table S5.2.1 *Taxonomic classification method of* ***(a)*** *autotrophic and* ***(b)*** *heterotrophic species groups based on different taxonomic classification sources (ITIS: Integrated Taxonomic Classification System)*

Species group	**Classification method**	**Taxonomic classification source**
(a) Autotrophs		
Cyanobacteria	Within the “Bacteria” kingdom, the phylum is "Cyanobacteria"	AlgaeBase
Macrophyte	Within the “Plantae” kingdom, the subkingdom is “Embryophyta”	PlantList
Silicon-based algae	Within the “Chromista” kingdom, the class is “Bacillariophyceae” or, within the “Plantae” kingdom, the family is “Desmidiaceae”[#]	AlgaeBase
Non-silicon-based algae	Within the “Bacteria” kingdom, the phylum is "Cyanobacteria" or, within the “Chromista” kingdom, the class is not “Bacillariophyceae” or, within the “Plantae” kingdom, the family is not “Desmidiaceae”	AlgaeBase
(b) Heterotroph		
Fish	Within the “Chordata” phylum, the class is "Chondrichthyes" or the superclass is “Osteichthyes”	Integrated Taxonomic Information System
Invertebrate	Within the “Animalia” kingdom, the phylum is not "Chordata"	Integrated Taxonomic Information System

[#] Although not all desmids may be silicon-based, we included them as part of this group for simplification

Appendix S5.2

Table S5.2.2 *Total phosphorus ^{10}log TP concentration range (log, mg P·L^{-1}) at which species* ***(a)*** *Cyanobacteria,* ***(b)*** *Fish,* ***(c)*** *Invertebrates,* ***(d)*** *Macrophytes,* ***(e)*** *Non-silicon-based algae,* ***(f)*** *Silicon-based algae in lakes and* ***(g)*** *Cyanobacteria,* ***(h)*** *Fish,* ***(i)*** *Invertebrates,* ***(j)*** *Macrophytes,* ***(k)*** *Non-silicon-based algae,* ***(l)*** *Silicon-based algae in streams.*

Species	**^{10}log TP**
(a) Cyanobacteria in lakes	
Cold	
Aphanocapsa delicatissima	-2.2 to -0.4
Aphanocapsa elachista	-1.7 to -0.4
Chamaesiphon subglobosus	-2.2 to 0.5
Chondrocystis dermochroa	-0.5 to -0.4
Chroococcus minutus	-2.2 to -0.4
Clastidium setigerum	-2 to -1.8
Geitlerinema amphibium	-2 to -1.2
Geitlerinema deflexum	-1.6 to -0.4
Gloeocapsa kuetzingiana	-2.7 to 0.5
Gloeocapsa ralfsiana	-2.2 to -0.4
Gloeocapsopsis magma	-2.2 to -1.2
Leptolyngbya angustissima	-2.2 to -0.9
Leptolyngbya antarctica	-2.2 to 0.5
Leptolyngbya fragilis	-2.7 to 0.5
Lyngbya lagerheimii	-1.6 to -0.4
Merismopedia tenuissima	-1.8 to 0.5
Microcystis flosaquae	-2 to -1.8
Nodularia harveyana	-1.8 to -1.4
Nostoc commune	-2.7 to -1
Oscillatoria tenuis	-2.2 to -0.9
Phormidium ambiguum	-2.7 to -0.9
Phormidium attenuatum	-1.8 to -0.9
Phormidium autumnale	-2.7 to 0.5
Phormidium chlorinum	-2.2 to 0.5
Phormidium corium	-2.7 to -0.2
Phormidium simplicissimum	-1.8 to -0.9
Pseudanabaena frigida	-2.7 to 0.5
Trichormus variabilis	-2.2 to -0.9
Temperate	
Anabaena solitaria	-1.4 to -1
Anabaenopsis circularis	-0.1 to 0.9
Aphanizomenon flosaquae	-1.3 to 0
Aphanocapsa delicatissima	-2 to -1.5
Aphanocapsa elachista	-2.2 to 0.9
Aphanocapsa holsatica	-1.7 to -1
Aphanothece nidulans	-2.2 to -1.6
Chroococcus dispersus	-2.2 to -2
Cylindrospermopsis raciborskii	-1.7 to -0.8
Cylindrospermum muscicola	-1.8 to -1.7
Dolichospermum flosaquae	-2 to -1.2
Heteroleibleinia pusilla	-2 to -1.1
Limnococcus limneticus	-2 to -1.6
Limnothrix planctonica	-0.7 to 0
Limnothrix redekei	-1.3 to -0.9
Merismopedia tenuissima	-2 to 0.5
Microcystis aeruginosa	-2 to 0.5
Microcystis flosaquae	-1.2 to 0
Microcystis pulverea	-1.4 to 1.1
Microcystis wesenbergii	-1.4 to -1
Oscillatoria angusta	-2 to -1.1
Planktolyngbya limnetica	-1.7 to -1
Planktolyngbya undulata	-2 to -1.1
Planktothrix agardhii	-1.4 to 0.5
Pseudanabaena galeata	-1.8 to -1.7
Pseudanabaena limnetica	-1.6 to 0.9
Spirulina laxissima	-1.7 to -1
Woronichinia naegeliana	-2 to -0.7
(Sub)tropical	
Aphanizomenon flosaquae	1.1 to 1.2
Aphanocapsa delicatissima	-1.4 to 1.2
Aphanocapsa holsatica	-2.3 to -1.3
Aphanocapsa incerta	-1.5 to -0.7

Species	^{10}log TP
Aphanocapsa minutissima	-2.3 to -1.1
Chroococcus aphanocapsoides	-2.3 to -1.3
Chroococcus dispersus	-0.2 to -0.1
Chroococcus giganteus	-0.2 to -0.1
Chroococcus varius	-0.2 to -0.1
Coelosphaerium dubium	0.9 to 1.4
Cyanodictyon imperfectum	-2.3 to -1.3
Cylindrospermopsis raciborskii	-2.3 to -0.1
Dolichospermum affine	-2.5 to -1
Dolichospermum crassum	-2.5 to -1.9
Dolichospermum planctonicum	-2.5 to -1.9
Gloeocapsa alpicola	-0.2 to -0.1
Gloeocapsa decorticans	-0.2 to -0.1
Gloeotrichia natans	1 to 1.5
Lyngbya aestuarii	1 to 1.2
Lyngbya major	-0.2 to -0.1
Merismopedia glauca	0.9 to 1.5
Merismopedia tenuissima	-1.5 to -0.7
Microcystis aeruginosa	-2.3 to 1.5
Microcystis flosaquae	-2.3 to -1.1
Microcystis ichthyoblabe	-2.3 to -1.1
Microcystis robusta	-2.3 to -1.1
Microcystis wesenbergii	1 to 1.5
Nostoc caeruleum	0.9 to 1.5
Oscillatoria angusta	0.9 to 1.5
Planktolyngbya contorta	-1.3 to -0.7
Planktolyngbya limnetica	-1.5 to -0.8
Pseudanabaena catenata	-2.3 to -0.1
Pseudanabaena limnetica	-0.2 to -0.1
Raphidiopsis mediterranea	-2.3 to -0.7
Spirulina laxa	1 to 1.2
Trichodesmium lacustre	-0.2 to -0.1
(b) Fish in lakes	
Cold	
Abramis brama	-2.2 to -0.9
Alburnus alburnus	-2.1 to -1.4
Anguilla anguilla	-2 to -1.3
Blicca bjoerkna	-1.9 to -0.9
Coregonus lavaretus	-2.1 to -1.7
Esox lucius	-2.7 to -0.9
Gymnocephalus cernuus	-2.2 to -0.9
Lota lota	-2.7 to -1.3
Osmerus eperlanus	-1.9 to -1
Perca fluviatilis	-2.7 to -0.9
Rutilus rutilus	-2.2 to -0.9
Salmo trutta	-2.7 to -2
Salvelinus alpinus	-2.7 to -1.6
Tinca tinca	-1.9 to -1.5
Temperate	
Abbottina rivularis	-2.3 to -0.6
Abramis brama	-2.2 to -0.2
Acheilognathus chankaensis	-2.3 to -0.6
Acheilognathus macropterus	-2.3 to -0.6
Alburnus alburnus	-2.2 to -0.2
Alosa pseudoharengus	-2.1 to -1.3
Anguilla anguilla	-1.9 to 0
Aphanius iberus	-2 to -1.4
Aspius aspius	-2.2 to -0.2
Australoheros facetus	-1.6 to -0.4
Barbus graellsii	-1.9 to -1.1
Blicca bjoerkna	-2.2 to -0.2
Carassius auratus	-1.3 to -1.2
Carassius carassius	-2.3 to -0.2
Carassius gibelio	-1.7 to -0.7
Catostomus catostomus	-2 to -0.6
Catostomus commersonii	-2 to -0.6
Characidium rachovii	-1.6 to -0.7
Charax stenopterus	-1.6 to -0.4
Cheirodon interruptus	0.1 to 0.6
Chondrostoma arcasii	-1.2 to 0.3
Chondrostoma miegii	-1.3 to -0.4
Cirrhinus molitorella	-1.4 to -0.8

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Species	^{10}log TP
Cnesterodon decemmaculatus	-1.6 to 0.4
Cobitis taenia	-2.2 to -0.2
Coregonus albula	-2.2 to -0.2
Coregonus artedi	-2.7 to -1.4
Coregonus clupeaformis	-2.7 to -1.4
Corydoras paleatus	-1.6 to 0.1
Cottus cognatus	-2 to -1.4
Cottus poecilopus	-2.2 to -0.2
Culter alburnus	-2 to -0.6
Culter dabry	-2 to -0.6
Culter mongolicus	-2.3 to -0.8
Culterichthys erythropterus	-2.3 to -0.6
Cyphocharax voga	-1.5 to 0.5
Cyprinus carpio	-2.2 to -0.2
Diapoma terofali	-1.1 to -0.4
Distoechodon hupeinensis	-2.3 to -0.6
Elopichthys bambusa	-1.4 to -0.8
Esox lucius	-2.2 to -0.2
Gasterosteus aculeatus	-2.2 to -0.2
Gobio gobio	-2.2 to -0.2
Gymnocephalus cernuus	-2.2 to -0.2
Hemibarbus maculatus	-1.2 to -0.6
Hemiculter bleekeri	-2.3 to -0.6
Hemiculter leucisculus	-2.3 to -0.6
Hoplias malabaricus	-1.9 to 0.5
Hypophthalmichthys molitrix	-2.2 to -0.2
Hypophthalmichthys nobilis	-2.2 to -0.2
Hyporhamphus intermedius	-2.3 to -0.6
Hypostomus commersoni	-1.6 to -0.4
Hypseleotris swinhonis	-2.3 to -0.8
Jenynsia multidentata	-1.6 to 0.1
Lepomis gibbosus	-1.9 to -0.3
Leucaspius delineatus	-2.2 to -0.2
Leuciscus cephalus	-1.7 to -1.5
Leuciscus leuciscus	-2.2 to -0.2
Lota lota	-2.7 to -0.2
Macropodus opercularis	-1.6 to -0.9
Margariscus margarita	-1.2 to -0.7
Mastacembelus sinensis	-1.2 to -0.6
Megalobrama amblycephala	-1.4 to -0.8
Micropterus dolomieu	-2.7 to -1.6
Micropterus salmoides	-1.9 to -0.4
Misgurnus anguillicaudatus	-2.3 to -0.6
Misgurnus fossilis	-2.2 to -0.2
Neosalanx taihuensis	-1.6 to -0.6
Odontesthes bonariensis	-1.9 to 0.5
Odontobutis obscura	-2.3 to -0.8
Oligosarcus jenynsii	-1.6 to 0.6
Oncorhynchus mykiss	-2.2 to -0.2
Osmerus eperlanus	-2.2 to -0.2
Paracanthobrama guichenoti	-1.4 to -0.6
Pelteobagrus fulvidraco	-2.3 to -0.8
Perca flavescens	-2.7 to -1.6
Perca fluviatilis	-2.2 to 0
Percopsis omiscomaycus	-2 to -1.4
Phalloceros caudimaculatus	-1.6 to -0.7
Phoxinus phoxinus	-2.2 to -0.2
Pimelodella australis	-1.6 to -1.3
Pimelodella laticeps	-0.1 to 0.1
Prosopium cylindraceum	-2.7 to -1.6
Pseudobrama simoni	-1.4 to -0.8
Pseudorasbora parva	-2.3 to -0.6
Pungitius pungitius	-2.2 to -0.2
Rhamdia quelen	-1.6 to -0.4
Rhinogobius giurinus	-2.3 to -0.6
Rhodeus amarus	-2.2 to -0.2
Rhodeus fangi	-2.3 to -0.9
Rhodeus ocellatus	-2.3 to -0.6
Rhodeus sericeus	-0.6 to -0.3
Rutilus rutilus	-2.2 to 0
Salaria fluviatilis	-1.3 to -0.9
Salmo salar	-2.1 to -1.6
Salmo trutta	-2.2 to -0.2
Salvelinus alpinus	-2.1 to -1.4

Species	^{10}log TP
Salvelinus namaycush	-2.7 to -1.4
Sarcocheilichthys nigripinnis	-2.3 to -0.6
Scardinius erythrophthalmus	-2.2 to 0
Silurus glanis	-2.2 to -0.2
Siniperca chuatsi	-2 to -0.6
Squalidus argentatus	-2.3 to -0.6
Squalidus nitens	-2.3 to -0.6
Squalius cephalus	-1.4 to -1.2
Synbranchus marmoratus	-1.6 to 0.4
Thymallus arcticus	-2 to -0.6
Tinca tinca	-2.2 to 0.3
Xenocypris davidi	-2 to -0.6
(Sub)tropical	
Ameiurus catus	-1.4 to -0.9
Dorosoma cepedianum	-1.4 to -0.9
Ictalurus punctatus	-1.4 to -0.9
Pomoxis nigromaculatus	-1.4 to -0.9
(c) Invertebrates in lakes	
Cold	
Ablabesmyia monilis	-2.7 to -1.5
Apsectrotanypus trifascipennis	-2.7 to -1.5
Arcteonais lomondi	-2.7 to -1.5
Bythotrephes longimanus	-2.4 to -2.1
Chironomus anthracinus	-2.7 to -1.5
Chironomus plumosus	-2.7 to -1.5
Chironomus salinarius	-2.7 to -1.5
Cladopelma viridula	-2.7 to -1.5
Cladotanytarsus mancus	-2.7 to -1.5
Cryptochironomus defectus	-2.7 to -1.5
Daphnia longispina	-1.1 to -0.6
Daphnia pulicaria	-2.7 to -1.7
Daphnia tenebrosa	-2.5 to -1.2
Demicryptochironomus vulneratus	-2.7 to -1.5
Diaphanosoma brachyurum	-2.1 to -0.6
Eurycercus lamellatus	-2.4 to -2.2
Heterotanytarsus apicalis	-2.7 to -1.5
Heterotrissocladius marcidus	-2.7 to -1.5
Heterotrissocladius subpilosus	-2.7 to -1.5
Holopedium gibberum	-2.7 to -2
Lamprodrilus isoporus	-2.7 to -1.5
Monodiamesa bathyphila	-2.7 to -1.5
Monoporeia affinis	-2.7 to -1.5
Mysis relicta	-2.7 to -1.5
Pagastiella orophila	-2.7 to -1.5
Pallasea quadrispinosa	-2.7 to -1.5
Polypedilum pullum	-2.7 to -1.5
Polyphemus pediculus	-2.1 to 0.2
Potamothrix hammoniensis	-2.7 to -1.5
Protanypus morio	-2.7 to -1.5
Schizothrix fragilis	-1.8 to 0.5
Sergentia coracina	-2.7 to -1.5
Specaria josinae	-2.7 to -1.5
Spirosperma ferox	-2.7 to -1.5
Stempellinella minor	-2.7 to -1.5
Stictochironomus rosenschoeldi	-2.7 to -1.5
Stylodrilus heringianus	-2.7 to -1.5
Uncinais uncinata	-2.7 to -1.5
Vejdovskyella comata	-2.7 to -1.5
Zalutschia zalutschicola	-2.7 to -1.5
Temperate	
Ablabesmyia longistyla	-1.3 to -0.4
Ablabesmyia monilis	-1.3 to -0.1
Ablabesmyia phatta	-1.4 to -1.1
Acanthocyclops bicuspidatus	-1 to -0.5
Acanthocyclops languidus	-1 to -0.5
Acanthocyclops robustus	-3 to 0.1
Acanthocyclops vernalis	-2.5 to -1.3
Acantholeberis curvirostris	-2.3 to -1.7
Acricotopus lucens	-1.7 to 0
Acroloxus lacustris	-1.3 to -0.3
Acroperus harpae	-2.7 to -0.9

Appendix S5.2

Species	^{10}log TP
Aeschna cyanea	-2.7 to -2
Aeschna juncea	-2.5 to -2.2
Agabus bipustulatus	-1.3 to 0.6
Agabus congener	0.5 to 0.6
Agabus solieri	0.5 to 0.6
Agabus sturmii	-1.3 to -0.4
Agraylea multipunctata	-1.3 to -1.2
Agraylea sexmaculata	-1.3 to -0.8
Agrypnia pagetana	-1.3 to -0.3
Agrypnia varia	-2.7 to -1.3
Allogamus antennatus	0.5 to 0.6
Allogamus auricollis	0.5 to 0.6
Allogamus uncatus	0.5 to 0.6
Alona affinis	-2.5 to -0.5
Alona azorica	-1.3 to -1
Alona circumfimbriata	-2.3 to -1.7
Alona costata	-3 to 0.1
Alona guttata	-2.3 to -0.9
Alona intermedia	-2.3 to -1.7
Alona karelica	-3 to -0.1
Alona nuragica	-1.3 to -0.7
Alona protzi	-0.4 to 0.1
Alona quadrangularis	-2.3 to -0.5
Alona rectangula	-3 to 0.1
Alona rustica	-2.3 to -1.7
Alona tenuicaudis	-1 to 0.1
Alona weltneri	0 to 0.1
Alonella excisa	-2.3 to -1
Alonella exigua	-2.3 to 0.1
Alonella nana	-3 to -0.1
Alonella rostrata	-1.5 to -0.9
Alonopsis americana	-2.3 to -1.7
Ameletus inopinatus	-2.7 to -2
Amphinemura triangularis	-2.7 to -2.2
Anabolia nervosa	-2 to -1.3
Anacaena globulus	-1.3 to -0.2
Anacaena limbata	-1.3 to -0.6

Species	^{10}log TP
Anatopynia plumipes	-1.3 to -0.7
Anisus vortex	-2 to -0.3
Anuraeopsis coelata	-0.7 to -0.1
Anuraeopsis fissa	-3 to 0.1
Aplexa hypnorum	-1.3 to -0.4
Apsectrotanypus trifascipennis	0.5 to 0.6
Aquarius paludulum	-1.4 to -1.3
Arctocorisa carinata	0.5 to 0.6
Arctodiaptomus alpinus	-2.4 to -2
Arctodiaptomus bacillifer	-1.1 to -0.2
Argyroneta aquatica	-2 to 0
Arrenurus batillifer	-1.3 to -0.6
Arrenurus bicuspidator	-1.3 to -0.8
Arrenurus buccinator	-1 to 0
Arrenurus crassicaudatus	-1.7 to 0.1
Arrenurus cuspidator	-1.3 to 0
Arrenurus globator	-2 to 0
Arrenurus inexploratus	-1.3 to 0
Arrenurus integrator	-1.3 to 0.1
Arrenurus latus	-1.3 to 0.1
Arrenurus securiformis	-1.3 to -0.9
Arrenurus sinuator	-1.3 to -0.8
Arrenurus tricuspidator	-1 to -0.8
Ascomorpha ecaudis	-3 to 0.1
Ascomorpha ovalis	-1.8 to -0.1
Ascomorpha saltans	-1.1 to -0.1
Asellus aquaticus	-1.3 to 0.1
Asplanchna brightwellii	-1.8 to -0.1
Asplanchna girodi	-1.8 to -1
Asplanchna priodonta	-2.3 to -0.1
Athripsodes aterrimus	-1.3 to 0
Attheyella trispinosa	-1.3 to -1
Bathyomphalus contortus	-2 to -0.2
Bithynia leachi	-1.3 to -0.3
Bithynia tentaculata	-1.3 to -0.2
Bosmina berolinensis	-1.7 to -0.7
Bosmina coregoni	-2.7 to -0.7

Species	^{10}log TP
Bosmina longirostris	-3 to 0.1
Bosminopsis deitersi	-2.7 to -1.6
Brachionus angularis	-1.8 to 0.1
Brachionus bidentata	-0.7 to 0.1
Brachionus calyciflorus	-3 to -0.1
Brachionus caudatus	-1.8 to -1.1
Brachionus diversicornis	-1.8 to -0.1
Brachionus falcatus	-1.8 to 0.1
Brachionus forficula	-1.8 to -0.1
Brachionus patulus	-1 to -0.1
Brachionus plicatilis	-0.6 to -0.1
Brachionus urceolaris	-2.7 to -0.1
Brachytron pratense	-1.3 to -0.7
Bradleycypris obliqua	-1.3 to -1
Branchiodrilus hortensis	-0.6 to -0.5
Branchiura sowerbyi	-0.8 to -0.5
Brevitobrilus stefanskii	-1 to 0
Caenis horaria	-1.5 to 0.1
Caenis luctuosa	-2 to -0.7
Caenis robusta	-1.7 to 0.1
Callicorixa praeusta	-1.5 to -0.1
Camptocercus rectirostris	-2.7 to -0.5
Candona neglecta	-1.3 to -1
Canthocamptus staphylinus	-1.3 to -0.7
Cataclysta lemnata	-1.3 to 0.1
Cephalodella exigua	-1.8 to -1.1
Cephalodella gibboides	-1 to -0.5
Cephalodella gigantea	-1 to -0.5
Cephalodella mus	-1 to -0.5
Ceriodaphnia cornuta	-2.7 to -1.6
Ceriodaphnia megops	-3 to -0.1
Ceriodaphnia pulchella	-1.1 to 0.1
Ceriodaphnia quadrangula	-2.7 to -0.7
Chaetocladius dentiforceps	0.5 to 0.6
Chaetogaster diaphanus	-1.3 to -0.1
Chaetogaster diastrophus	-0.6 to -0.5
Chaetogaster limnaei	-0.6 to -0.5

Species	^{10}log TP
Chaoborus crystallinus	-1.3 to 0.1
Chaoborus flavicans	-2.5 to 0
Chaoborus trivittatus	-2.5 to -1.5
Chironomus plumosus	-1.3 to 0.6
Chironomus salinarius	-1.3 to -0.2
Chironomus thummi	0.5 to 0.6
Chydorus bicornutus	-2.3 to -1.7
Chydorus brevilabris	-2.3 to -1.7
Chydorus gibbus	-3 to -0.1
Chydorus linguilabris	-2.3 to -1.7
Chydorus sphaericus	-3 to 0.1
Cladotanytarsus mancus	-0.7 to 0.6
Clinotanypus nervosus	-1.5 to -0.3
Cloeon dipterum	-2 to 0.5
Cloeon simile	-1.3 to -0.8
Codonella cratera	-2.5 to -0.4
Colurella adriatica	-2.7 to -0.6
Colurella tesselata	-2.7 to -0.6
Colymbetes fuscus	-1.3 to -0.4
Conochilus dossuarius	-0.6 to -0.1
Conochilus hippocrepis	-2.3 to -1.8
Conochilus unicornis	-0.7 to -0.1
Copelatus haemorrhoidalis	-1.3 to -0.4
Cordulia aenea	-2 to -0.8
Corixa affinis	-1.3 to -0.1
Corixa panzeri	-1.3 to -0.1
Corixa punctata	-1.4 to 0.1
Corophium curvispinum	-1.3 to 0
Corophium volutator	-1.3 to 0.4
Corynoneura arctica	0.5 to 0.6
Corynoneura lacustris	-1.3 to 0.6
Corynoneura lobata	0.5 to 0.6
Corynoneura scutellata	-1.3 to 0.6
Cricotopus cylindraceus	-1.3 to -0.4
Cricotopus laricomalis	0.5 to 0.6
Cricotopus myriophylli	-2.5 to -2.1
Cricotopus ornatus	-1.3 to -0.1

Appendix S5.2

Species	^{10}log TP
Cricotopus sylvestris	-2 to 0.1
Cricotopus trifasciatus	-0.6 to -0.5
Cyclops abyssorum	-2.5 to -2
Cyclops vicinus	-2.7 to -1.6
Cymatia bonsdorffii	-1.3 to -0.1
Cymatia coleoptrata	-1.3 to -0.3
Cypridopsis hartwigi	-1.3 to -0.8
Cyrnus flavidus	-1.3 to -0.2
Daphnia ambigua	-2.4 to -0.4
Daphnia carinata	-2.7 to -1.6
Daphnia catawba	-2.4 to -2.1
Daphnia cucullata	-1.7 to -0.7
Daphnia dubia	-2.1 to -1.9
Daphnia galeata	-1.7 to -0.3
Daphnia hyalina	-2.7 to 0
Daphnia longiremis	-2.4 to -1.9
Daphnia longispina	-2.4 to 0
Daphnia mendotae	-2.4 to -1.6
Daphnia pulex	-2.7 to -0.2
Daphnia pulicaria	-2.4 to -1.9
Demicryptochironomus vulneratus	-1.4 to -1.3
Dendrocoelum lacteum	-1.3 to -0.3
Dero digitata	-1 to -0.8
Diacyclops bicuspidatus	-1.3 to -0.7
Diacyclops bisetosus	-1 to -0.7
Diacyclops thomasi	-2.1 to -1.3
Diaphanosoma brachyurum	-2.7 to 0.1
Dicrotendipes lobiger	-1.3 to -0.4
Dicrotendipes nervosus	-2 to 0.1
Dicrotendipes notatus	-1.3 to -0.7
Diplogaster rivalis	-1 to 0
Disparalona acutirostris	-2.3 to -1.7
Disparalona rostrata	-2.7 to -1.6
Dorylaimus stagnalis	-1 to 0
Dreissena polymorpha	-1.4 to -0.5
Dryops luridus	-1.3 to 0.1
Dugesia lugubris	-1.3 to 0
Dugesia tigrina	-1.3 to -0.7
Dunhevedia crassa	-3 to -0.1
Dytiscus circumflexus	-1.3 to -0.1
Dytiscus marginalis	-1.3 to -0.8
Ecnomus tenellus	-1.3 to -0.3
Einfeldia dissidens	-1.3 to -0.9
Enallagma cyathigerum	-2.2 to -0.6
Endochironomus albipennis	-2 to 0.1
Endochironomus dispar	-2 to 0.6
Endochironomus impar	-1.3 to -0.4
Endochironomus tendens	-2 to 0.1
Enochrus testaceus	-1.3 to 0.1
Eodiaptomus sinensis	-2.7 to -1.6
Erpobdella octoculata	-1.3 to 0.1
Erpobdella testacea	-1.3 to 0.6
Erythromma najas	-1.4 to -0.6
Estatheroporus gauthieri	-1.3 to -0.7
Ethmolaimus pratensis	-1 to 0
Eubosmina longispina	-2.3 to -1.7
Euchlanis dilatata	-2.7 to -0.6
Euchlanis triquetra	-3 to -0.1
Eucyclops euacanthus	-2.7 to -1.6
Eucyclops serrulatus	-2.7 to -0.8
Eucypris virens	-1.3 to -0.7
Eudiaptomus gracilis	-0.6 to 0
Eumonhystera filiformis	-1 to 0
Eurycercus lamellatus	-1.5 to -0.5
Eylais infundibulifera	-1.3 to -0.7
Filinia cornuta	-0.7 to -0.1
Filinia longiseta	-2.7 to -0.1
Filinia minuta	-1.8 to -0.1
Filinia opoliensis	-1 to 0.1
Filinia terminalis	-3 to 0.1
Gammarus duebeni	-1.3 to 0
Gammarus lacustris	-2 to -0.9
Gammarus pulex	-1.3 to -0.3
Gammarus tigrinus	-1.4 to 0

Species	^{10}log TP
Gammarus zaddachi	-1.3 to 0.4
Gerris argentatus	-1.4 to -1.3
Gerris lacustris	-1.3 to 0
Gerris odontogaster	-1.5 to -0.8
Gerris thoracicus	-1.3 to -0.8
Glossiphonia complanata	-2 to 0.1
Glossiphonia heteroclita	-1.3 to -0.2
Glyptotendipes barbipes	-1.3 to 0
Glyptotendipes pallens	-2 to 0.1
Glyptotendipes paripes	-1.4 to -1
Glyptotendipes testaceus	-0.6 to -0.5
Graphoderus cinereus	-1.3 to -0.4
Graptodytes pictus	-1.4 to 0.1
Graptoleberis testudinaria	-2.7 to -0.5
Gyraulus albus	-1.3 to -0.3
Gyraulus crista	-2 to -0.1
Gyrinus paykulli	-1.3 to -0.2
Haliplus apicalis	-1.3 to 0
Haliplus confinis	-1.3 to -0.4
Haliplus flavicollis	-1.3 to 0.1
Haliplus fluviatilis	-0.8 to -0.4
Haliplus heydeni	-1.3 to -0.2
Haliplus immaculatus	-1.3 to 0.1
Haliplus lineatocollis	-0.8 to 0.5
Haliplus ruficollis	-1.4 to 0.1
Halocladius varians	-1.3 to 0.4
Helobdella nuda	-0.6 to -0.5
Helobdella stagnalis	-2 to 0.1
Helochares lividus	-1.3 to -0.4
Helochares obscurus	-2 to 0.1
Helophorus aequalis	-1.3 to -0.4
Helophorus brevipalpis	-1.3 to 0.5
Helophorus glacialis	0.5 to 0.6
Hemiclepsis marginata	-1.3 to -0.6
Hesperocorixa castanea	-1.3 to -0.4
Hesperocorixa linnaei	-2 to -0.3
Hesperocorixa moesta	-1.3 to -0.8
Hesperocorixa sahlbergi	-1.3 to -0.6
Hexarthra intermedia	-0.6 to -0.1
Hexarthra mira	-3 to 0.1
Hippeutis complanatus	-2 to -0.4
Holocentropus picicornis	-1.3 to -0.6
Holocentropus stagnalis	-1.1 to -0.6
Holopedium gibberum	-2.4 to -1.7
Hyalella azteca	-2.4 to -0.8
Hydrachna cruenta	-1.3 to -0.7
Hydrachna globosa	-1.3 to -0.7
Hydrachna skorikowi	-1.3 to -0.1
Hydrobia ventrosa	-1.3 to 0.4
Hydrobius fuscipes	-1.3 to 0
Hydrodroma despiciens	-1.7 to -0.1
Hydroglyphus geminus	-1.3 to -0.3
Hydroporus foveolatus	0.5 to 0.6
Hydroporus palustris	-1.4 to 0.6
Hydroporus striola	-1.3 to -0.4
Hydroporus umbrosus	-2 to -1.3
Hydrovatus cuspidatus	-2 to 0.1
Hydryphantes dispar	-2 to -0.4
Hygrobates longipalpis	-1.4 to -1.2
Hygrobia hermanni	-1.3 to 0
Hygrotus confluens	-1.3 to -0.9
Hygrotus decoratus	-1.3 to -0.4
Hygrotus impressopunctatus	-1.3 to -0.3
Hygrotus inaequalis	-1.3 to 0.1
Hygrotus nigrolineatus	-1.3 to 0.1
Hygrotus versicolor	-2 to -0.4
Hyphydrus ovatus	-1.3 to -0.5
Idotea chelipes	-1.3 to 0.4
Ilybius fenestratus	-1 to -0.8
Ilybius subaeneus	-1.3 to -0.8
Ilyocryptus agilis	-2.7 to -1.6
Ilyocryptus sordidus	-3 to -0.1
Ilyocypris decipiens	-1.3 to -1
Ischnura elegans	-2 to -0.1

Appendix S5.2

Species	^{10}log TP
Jaera ischiosetosa	-1.3 to 0
Kellicottia longispina	-2.3 to -1.8
Keratella cochlearis	-3 to 0.1
Keratella delicata	-0.6 to -0.1
Keratella hiemalis	-2.5 to -2
Keratella quadrata	-3 to 0.1
Keratella serrulata	-2.7 to -0.6
Keratella tropica	-2 to -0.6
Keratella valga	-2 to 0.1
Kurzia latissima	-2.3 to -1.7
Laccobius bipunctatus	-1.2 to -0.4
Laccobius colon	-1.3 to -0.8
Laccobius minutus	-2 to 0.1
Laccophilus minutus	-1.7 to -0.1
Latona parviremis	-2.3 to -1.7
Latona setifera	-2.3 to -1.7
Lecane aculeata	-1.8 to -0.5
Lecane bifurca	-1 to -0.5
Lecane clara	-2.7 to -0.6
Lecane inermis	-1.8 to -0.5
Lecane ligona	-2.7 to -0.6
Lecane lunaris	-2.7 to -0.1
Lecane mira	-2.3 to -2
Lecane mylacris	-2.7 to -0.6
Lecane pyriformis	-1 to -0.5
Lecane quadridentata	-3 to -0.1
Lecane signifera	-2.7 to -0.6
Lecane stichaea	-2.7 to -0.6
Lepadella elliptica	-1 to -0.5
Leptodora kindtii	-2.7 to -0.9
Leptophlebia vespertina	-2.7 to -1.1
Lestes sponsa	-2.2 to -0.6
Leuctra aurita	-2.7 to -2
Leuctra digitata	-2.7 to -2
Leuctra fusca	-2.7 to -2
Leuctra handlirschi	-2.5 to -2.2
Leuctra nigra	-2.5 to -2.2
Leydigia acanthocercoides	-1.1 to -0.5
Leydigia leydigi	-2.7 to -0.5
Libellula depressa	-0.8 to 0.1
Libellula quadrimaculata	-1.3 to -0.4
Liliferotrocha subtilis	-0.7 to -0.1
Limnephilus affinis	-1.4 to -0.7
Limnephilus coenosus	0.5 to 0.6
Limnephilus flavicornis	-1.4 to -1.1
Limnephilus griseus	-2.5 to -2.2
Limnephilus lunatus	-1.3 to -0.6
Limnephilus marmoratus	-1.4 to -1.3
Limnephilus rhombicus	-2.7 to -0.6
Limnephilus stigma	-2.5 to -2
Limnephilus vittatus	-1.5 to -1.4
Limnesia maculata	-1.4 to -0.7
Limnesia polonica	-1 to -0.8
Limnesia undulata	-1.3 to -0.3
Limnesia undulatoides	-1.7 to -1.3
Limnodrilus claparedeanus	-1.2 to -1
Limnodrilus hoffmeisteri	-1.3 to -0.4
Lumbriculus variegatus	-2 to 0.1
Lymnaea stagnalis	-1.3 to 0
Macrothrix rosea	-1.3 to -1
Megacyclops gigas	-1.3 to -0.7
Melampophylax mucoreus	0.5 to 0.6
Mesocyclops edax	-2.1 to -1.3
Mesocyclops nothius	-2.7 to -1.6
Metacyclops mendocinus	-0.8 to -0.6
Microchironomus tener	-1.3 to -0.7
Microcodon clavus	-2.7 to -2.2
Microcyclops rubellus	-1.3 to -1
Mideopsis orbicularis	-1.4 to -0.7
Mixodiaptomus lilljeborgi	-1.3 to -0.7
Moina micrura	-2.7 to -0.5
Molanna angustata	-1.4 to -1
Monhystera fasciculata	-1 to 0
Mononchus aquaticus	-1 to 0

Species	^{10}log TP
Monopelopia tenuicalcar	-1.2 to -0.8
Monospilus dispar	-2.3 to -1.7
Monostyla bulla	-1.8 to -1
Mystacides azurea	-2.7 to -2.2
Mystacides longicornis	-1.7 to -0.3
Mystacides niger	-1 to 0
Myxas glutinosa	-1 to -0.8
Nemotelus notatus	-1.3 to 0
Nemoura cinerea	-2.7 to 0.6
Nemurella picteti	-2.7 to 0.6
Neodiaptomus schmackeri	-2.7 to -1.6
Neodiaptomus yangtsekiangensis	-2.7 to -1.6
Neomysis integer	-1.3 to 0
Nepa cinerea	-1.3 to -0.3
Nereis diversicolor	-1.3 to 0.4
Neumania deltoides	-1.4 to -0.8
Neumania vernalis	-1.4 to -0.8
Neutrodiaptomus alatus	-2.7 to -1.6
Noterus clavicornis	-2 to 0.1
Noterus crassicornis	-1.3 to -0.4
Notholca squamula	-2.5 to -0.1
Notodiaptomus incompositus	-0.8 to -0.6
Notommata glyphura	-3 to -0.1
Notonecta obliqua	-1.3 to -0.8
Notonecta viridis	-1.3 to -0.1
Ochthebius marinus	-2 to -1.5
Ochthebius minimus	-1.3 to -0.9
Odontocerum albicorne	-2.2 to 0.6
Odontomyia argentata	-1.3 to -0.8
Oecetis furva	-1.7 to -0.5
Oecetis lacustris	-1.3 to -0.4
Oecetis ochracea	-2 to -0.1
Oligotricha striata	-2.5 to 0.6
Ophidonais serpentina	-1.3 to 0.1
Ophryoxis brevicaudis	-2.3 to -1.7
Oxyurella tenuicaudis	-1.1 to -0.5
Palaemon longirostris	-1.3 to -0.7
Palaemonetes varians	-1.3 to 0.4
Parachironomus arcuatus	-1.4 to 0
Parachironomus varus	-2 to 0.1
Paracladius alpicola	0.5 to 0.6
Paracladopelma camptolabis	0.5 to 0.6
Parakiefferiella coronata	0.5 to 0.6
Parakiefferiella triquetra	0.5 to 0.6
Paralimnocythere psammophila	-1.3 to -0.7
Paralona pigra	-2.3 to -1.7
Paramerina cingulata	-1.3 to -1
Paratanytarsus austriacus	-1.3 to 0.6
Paratanytarsus laccophilus	0.5 to 0.6
Paratrichocladius nivalis	0.5 to 0.6
Paratrichocladius skirwithensis	0.5 to 0.6
Parorthocladius nudipennis	0.5 to 0.6
Peltodytes caesus	-1.3 to -0.4
Phryganea bipunctata	-2.7 to -0.3
Phryganea striata	-2.2 to -2
Physa acuta	-1.3 to -0.3
Physa fontinalis	-1.3 to 0.1
Piona alpicola	-1.3 to 0
Piona carnea	-1.3 to -0.1
Piona clavicornis	-1.3 to -0.8
Piona coccinea	-1.3 to -0.7
Piona conglobata	-2 to 0
Piona variabilis	-2 to 0
Pionopsis lutescens	-2 to 0
Piscicola geometra	-1.3 to 0.1
Pisidium henslowanum	-1.4 to -1
Pisidium nitidum	-1 to -0.8
Pisidium oasertanum	0.5 to 0.6
Pisidium personatum	-1.3 to -0.6
Planorbarius corneus	-2 to -1.2
Planorbis planorbis	-1.5 to 0.1
Plectrocnemia conspersa	-2.5 to 0.6
Pleuroxus aduncus	-1.5 to -0.9
Pleuroxus denticulatus	-2.3 to -1.7

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Species	^{10}log TP
Pleuroxus laevis	-2.3 to -1.7
Pleuroxus striatus	-2.3 to -1.7
Polyarthra dolichoptera	-2.7 to -0.1
Polyarthra major	-2.7 to -0.6
Polyarthra remata	-2.7 to -0.6
Polyarthra vulgaris	-3 to 0.1
Polycelis nigra	-1.4 to -0.6
Polycelis tenuis	-2 to -0.1
Polycentropus flavomaculatus	-2.5 to 0.6
Polypedilum bicrenatum	-1.3 to -0.1
Polypedilum convictum	-2 to -0.8
Polypedilum nubeculosum	-1.4 to 0
Polypedilum pedestre	-2 to -0.8
Polypedilum sordens	-2 to 0.1
Polyphemus pediculus	-2.3 to -0.6
Pompholyx complanata	-0.6 to -0.1
Pompholyx sulcata	-1.8 to -0.1
Potamopyrgus antipodarum	-1.3 to 0
Potamothrix moldaviensis	-1.3 to -0.4
Proales parasita	-0.7 to -0.1
Proalides digitus	-0.7 to -0.1
Proalides tentaculata	-0.7 to -0.1
Proasellus meridianus	-1.3 to -0.1
Procladius chloreus	-0.8 to -0.6
Procladius choreus	-1.3 to -0.1
Prodiamesa olivacea	0.5 to 0.6
Propsilocerus akamusi	-0.8 to -0.6
Protanypus caudatus	0.5 to 0.6
Protonemura auberti	-2.5 to -2
Protonemura hrabei	-2.7 to -2
Psammoryctides barbatus	-1.4 to -1.3
Psectrocladius barbimanus	-1.3 to -0.8
Psectrocladius limbatellus	0.5 to 0.6
Psectrocladius platypus	-1.4 to 0.1
Psectrocladius sordidellus	-2 to 0.6
Psectrotanypus varius	-1.3 to 0.5
Pseudochydorus globosus	-3 to -0.1

Species	^{10}log TP
Pseudodiamesa branickii	0.5 to 0.6
Pseudodiamesa nivosa	0.5 to 0.6
Pseudosmittia forcipatus	-1.3 to -0.8
Pyrrhosoma nymphula	-2.7 to -0.6
Radix ovata	-1.5 to 0.1
Radix peregra	-1.7 to 0.6
Radix swinhoei	-0.6 to -0.5
Ranatra linearis	-1.7 to -0.2
Rhantus exsoletus	-2 to -0.6
Rhantus frontalis	-1.4 to -0.1
Rheocricotopus effusus	0.5 to 0.6
Rhinoglena frontalis	-1.8 to -0.1
Rhyacophila italica	0.5 to 0.6
Rhynchnotalona falcata	-2.3 to -1.7
Rhynchotalona falcata	-2.7 to -1.6
Scapholeberis mucronata	-2.7 to -0.6
Scapholeberis rammneri	-1.3 to -1
Schmackeria forbesi	-2.7 to -1.6
Segmentina nitida	-1.3 to -0.7
Sialis lutaria	-2.7 to 0
Sida crystallina	-2.7 to -0.9
Sigara distincta	-1.3 to -0.6
Sigara falleni	-1.4 to 0.1
Sigara lateralis	-1.7 to 0.1
Sigara scotti	-1.5 to -0.9
Sigara semistriata	-1.4 to -1.1
Sigara stagnalis	-1.3 to 0.4
Sigara striata	-1.7 to 0.1
Simocephalus serrulatus	-2.7 to -1.6
Simocephalus vetuloides	-2.7 to -1.6
Simocephalus vetulus	-2.7 to -0.5
Sinantherina socialis	-0.6 to -0.1
Sinocalanus doerri	-2.7 to -1.6
Siphlonurus lacustris	-2.7 to 0.6
Sphaerium corneum	-1.3 to -0.5
Sphaerium lacustre	-0.8 to -0.6
Sphaeroma rugicauda	-1.3 to 0.4

Species	^{10}log TP
Spirosperma ferox	-1.4 to -1.3
Stagnicola palustris	-1.3 to 0.1
Stephanoceros fimbriatus	-2.7 to -0.6
Stictotarsus griseostriatus	0.5 to 0.6
Stilociadius montanus	0.5 to 0.6
Streblospio shrubsolii	-1.3 to -1.1
Stylaria fossularis	-0.6 to -0.5
Stylaria lacustris	-1.7 to 0.1
Sympetrum striolatum	-1.3 to -0.6
Synchaeta oblonga	-1.8 to -0.1
Synchaeta pectinata	-2.2 to -0.1
Synchaeta stylata	-2 to -0.1
Synchaeta tremula	-2.5 to -1.1
Tanypus chinensis	-0.8 to -0.6
Tanypus kraatzi	-1.3 to -0.6
Tanypus punctipennis	-0.8 to -0.6
Tanytarsus pallidicornis	0.5 to 0.6
Theodoxus fluviatilis	-1.3 to -0.3
Thermocyclops hyalinus	-2.7 to -1.6
Thermocyclops taihokuensis	-2.7 to -1.6
Theromyzon tessulatum	-1.7 to 0
Tiphys ornatus	-2 to -1.3
Tobrilus gracilis	-1 to 0
Tobrilus wesenbergi	-1 to 0
Triaenodes bicolor	-2 to 0
Tribelos intextus	-1.4 to -1
Trichocerca capucina	-0.6 to -0.4
Trichocerca cylindrica	-1.8 to -0.1
Trichocerca divon-nuttalli	-0.7 to -0.1
Trichocerca elongata	-3 to 0.1
Trichocerca gracilis	-1.8 to -0.1
Trichocerca longiseta	-2.7 to -0.6
Trichocerca myersi	-2.3 to -1.8
Trichocerca pusilla	-1.8 to -0.1
Trichocerca rousseleti	-1.8 to -1
Trichocerca similis	-1 to -0.1
Trichocerca stylata	-2.3 to -0.1
Trichocerca vargai	-1.8 to -1.1
Trichocerca vernalis	-1 to -0.5
Trichotria tetractis	-2.7 to -0.6
Tropocyclops extensus	-2.1 to -1.3
Tropocyclops meridionalis	-0.8 to -0.6
Tropodiaptomus oryzanus	-2.7 to -1.6
Tvetenia calvescens	0.5 to 0.6
Valvata cristata	-1.3 to 0
Valvata piscinalis	-1.4 to 0
Xeric	
Branchinecta packardi	-0.4 to 0.6
Eretes sticticus	-0.2 to 0.6
Eulimnadia texana	-0.4 to 0.6
Potamocypris compressa	-0.2 to 0.6
Triops longicaudatus	-0.4 to 0.6
(Sub)tropical	
Caladomyia ortoni	-2.3 to -1.9
Diaptomus dorsalis	-1.5 to -0.7
Eubosmina tubicen	-1.5 to -0.9
Limnodrilus hoffmeisteri	-2.3 to -2.1
Tropocyclops prasinus	-1.5 to -0.7
(d) Macrophytes in lakes	
Cold	
Eleocharis palustris	-2 to -1.3
Equisetum fluviatile	-2 to -1.3
Lobelia dortmanna	-2 to -1.3
Myriophyllum alterniflorum	-2 to -1.3
Nuphar lutea	-2 to -1.3
Nymphaea candida	-2 to -1.3
Phragmites australis	-2 to -1.3
Potamogeton natans	-2 to -1.3
Potamogeton perfoliatus	-2 to -1.3
Ranunculus peltatus	-2 to -1.3
Schoenoplectus lacustris	-2 to -1.3

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Species	^{10}log TP
Sparganium angustifolium	-2 to -1.3
Sparganium emersum	-2 to -1.3
Sparganium erectum	-2 to -1.3
Stratiotes aloides	-1.6 to -0.6
Typha angustifolia	-2 to -1.3
Typha latifolia	-2 to -1.3
Temperate	
Achillea salicifolia	-1.6 to -1
Acorus calamus	-1.6 to -0.1
Agrostis pourretii	-1.3 to -0.7
Agrostis stolonifera	-1.6 to -1
Alisma gramineum	-1.6 to -1
Alisma plantago-aquatica	-1.6 to 0
Alopecurus aequalis	-1.6 to -1
Alopecurus bulbosus	-1.3 to -0.7
Andromeda glaucophylla	-2.5 to -1.7
Antinoria agrostidea	-1.2 to 0.3
Antinoria insularis	-1.3 to -0.7
Apium crassipes	-1.3 to -1
Bellis annua	-1.3 to -0.7
Berula erecta	-2.5 to -1.4
Bidens beckii	-1.6 to -1.3
Bidens cernua	-1.6 to 0.8
Bidens radiata	-1.6 to -1
Bidens tripartita	-1.6 to -1
Brasenia schreberi	-2.5 to -1.3
Butomus umbellatus	-1.6 to -1
Cabomba caroliniana	-1.6 to -1.3
Calamagrostis canescens	-1.6 to -1
Calamagrostis purpurea	-1.6 to -1
Calamaria setacea	-2.7 to -1.6
Callitriche brutia	-1.5 to -1.3
Callitriche hamulata	-1.6 to -0.8
Callitriche heterophylla	-1.6 to -1.3
Callitriche palustris	-2.7 to -0.5
Callitriche stagnalis	-1.3 to -0.7
Caltha palustris	-1.6 to -1
Calystegia sepium	-1.6 to -1
Carex acuta	-1.6 to -1
Carex divisa	-1.3 to -0.7
Carex lasiocarpa	-1.6 to -0.5
Carex lurida	-2.5 to -0.5
Carex pseudocyperus	-0.3 to 0.8
Carex riparia	-1.4 to -1.1
Carex vulpina	-1.6 to -1
Ceratophyllum demersum	-3 to 0.2
Ceratophyllum muricatum subsp. Australe	-1.6 to -0.5
Ceratophyllum submersum	-1.5 to -1.3
Chamaedaphne calyculata	-2.5 to -0.5
Cicuta virosa	-1.6 to -1
Cladium mariscus	-1.6 to -1
Comarum palustre	-1.6 to -1
Crassula vaillantii	-1.3 to -0.7
Cyperus fuscus	-1.6 to -1
Damasonium alisma	-1.3 to -0.8
Dulichium arundinaceum	-2.5 to -0.5
Eichhornia crassipes	-1.6 to -1.3
Elatine americana	-1.6 to -1.3
Elatine hydropiper	-1.6 to -1
Elatine minima	-1.6 to -1.3
Elatine triandra	-1.6 to -1.3
Eleocharis acicularis	-2.5 to -1
Eleocharis palustris	-1.6 to 0
Eleocharis parvula	-1.6 to -1.3
Eleocharis robbinsii	-1.6 to -0.5
Eleocharis uniglumis	-1.6 to -1
Elodea canadensis	-2 to 0.8
Elodea nuttallii	-1.9 to -0.5
Epilobium hirsutum	-1.6 to -1
Epilobium palustre	-1.6 to -1
Epipactis palustris	-1.6 to -1
Equisetum fluviatile	-1.6 to 0.8
Equisetum palustre	-1.6 to -1

Species	^{10}log TP
Eriocaulon aquaticum	-2.5 to -1.3
Eriocaulon sexangulare	-2.5 to 0.8
Euphrasia officinalis	-1.6 to -1
Fontinalis antipyretica	-1.6 to -1.3
Fontinalis novae-angliae	-2.5 to -0.5
Galium aparine	-1.6 to -1
Galium palustre	-1.6 to -1
Glossostigma cleistanthum	-1.6 to -1.3
Glyceria fluitans	-1.6 to 0.3
Glyceria maxima	-2 to 0
Glyceria spicata	-1.3 to -0.7
Gratiola aurea	-1.6 to -1.3
Groenlandia densa	-2 to -1.7
Heteranthera dubia	-1.6 to -1.3
Hydrilla verticillata	-1.9 to -0.7
Hydrocharis dubia	-1.6 to -1.4
Hydrocharis morsus-ranae	-1.6 to -1
Hypericum mutilum subsp. Boreale	-2.5 to -1.7
Illecebrum verticillatum	-1.3 to -1
Inula britannica	-1.6 to -1
Iris pseudacorus	-1.7 to 0
Isoetes eatonii	-1.6 to -1.3
Isoetes echinospora	-1.6 to -1.3
Isoetes engelmannii	-1.6 to -1.3
Isoetes lacustris	-2.7 to -1.2
Isoetes riparia	-1.6 to -1.3
Isoetes tiguliana	-1.3 to -0.7
Isoetes tuckermanii	-2.5 to -1.3
Isoetes tuckermanii subsp. Acadiensis	-1.6 to -1.3
Isoetes velata	-1.3 to -0.8
Jacobaea paludosa	-1.6 to -1
Juncus articulatus	-1.6 to -1
Juncus bufonius	-1.6 to -1
Juncus bulbosus	-2.2 to -2
Juncus canadensis	-2.5 to -1.7
Juncus effusus	-1.6 to 0.8
Juncus marginatus	-2.5 to -1.7
Juncus militaris	-2.5 to -1.7
Juncus pelocarpus	-2.5 to -1.3
Juncus pygmaeus	-1.3 to -0.7
Juncus subnodulosus	-1.3 to -1
Kalmia polifolia	-2.5 to -1.7
Lathyrus japonicus subsp. Maritimus	-1.6 to -1
Lathyrus palustris	-1.6 to -1
Lemna gibba	-1.6 to -1
Lemna minor	-2 to 0.8
Lemna trisulca	-3 to 0
Leymus arenarius	-1.6 to -1
Littorella uniflora	-2.7 to -1.2
Lobelia dortmanna	-2.7 to -1.2
Lotus pedunculatus	-1.3 to -1
Ludwigia palustris	-1.6 to -0.5
Lycopus europaeus	-1.6 to -1
Lysimachia terrestris	-1.6 to -0.5
Lysimachia thyrsiflora	-1.6 to -1
Lysimachia vulgaris	-1.6 to -1
Lythrum salicaria	-1.6 to -1
Marsilea polycarpa	-1.6 to -1.3
Mentha aquatica	-1.6 to -1
Mentha arvensis	-1.6 to -1
Mentha pulegium	-1.3 to -1
Mentha verticillata	-1.6 to -1
Menyanthes trifoliata	-1.6 to -1
Middendorfia borysthenica	-1.3 to -0.7
Myosotis scorpioides	-1.6 to -1
Myosotis sicula	-1.3 to -0.7
Myosoton aquaticu	-1.6 to -1
Myrica gale	-2.5 to -0.5
Myriophyllum alterniflorum	-2.3 to 0.3
Myriophyllum heterophyllum	-1.6 to -1.3
Myriophyllum humile	-1.6 to -1.3
Myriophyllum quitense	-1.9 to -0.9
Myriophyllum sibiricum	-3 to -1
Myriophyllum spicatum	-3 to 0.2

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Species	^{10}log TP
Myriophyllum tenellum	-1.6 to -1.3
Myriophyllum verticillatum	-1.8 to -0.1
Najas flexilis	-3 to -1
Najas gracillima	-1.6 to -1.3
Najas guadalupensis	-1.6 to -1.3
Najas marina	-3 to -0.7
Najas minor	-1.6 to -1.3
Nuphar lutea	-2 to -0.1
Nuphar lutea subsp. Variegata	-1.8 to -1.3
Nuphar pumila	-1.6 to -1
Nuphar variegatum	-2.5 to 0.8
Nymphaea alba	-1.6 to -0.4
Nymphaea odorata	-2.5 to 0.8
Nymphoides cordata	-2.5 to -1.3
Nymphoides peltatum	-1.8 to -0.9
Odontites litoralis	-1.6 to -1
Oenanthe aquatica	-1.6 to -1
Pedicularis palustris	-1.6 to -1
Persicaria hydropiper	-1.6 to -1
Persicaria lapathifolia	-1.6 to -1
Petasites spurius	-1.6 to -1
Phalaris arundinacea	-1.6 to -1
Phragmites australis	-1.8 to 0.2
Polypogon maritimus	-1.3 to -0.8
Pontederia cordata	-2.5 to 0.8
Potamogeton acutifolius	-1.6 to -0.4
Potamogeton alpinus	-2.5 to -1.3
Potamogeton amplifolius	-1.6 to -1.3
Potamogeton berchtoldii	-2.5 to -0.5
Potamogeton bicupulatus	-1.6 to -1.3
Potamogeton compressus	-1.9 to -1
Potamogeton confervoides	-2.5 to -1.3
Potamogeton crispus	-2 to -0.1
Potamogeton diversifolius	-1.6 to -1.3
Potamogeton epihydrus	-2.5 to -0.5
Potamogeton foliosus	-1.8 to 0.8
Potamogeton friesii	-1.6 to -1
Potamogeton gramineus	-3 to 0.8
Potamogeton illinoensis Morong	-3 to -1
Potamogeton natans	-1.8 to 0.8
Potamogeton nodosus	-1.8 to -1.1
Potamogeton oakesianus	-2.5 to -0.5
Potamogeton obtusifolius	-1.6 to -1
Potamogeton perfoliatus	-2.5 to -1
Potamogeton praelongus	-2.5 to -1
Potamogeton pulcher	-1.6 to -1.3
Potamogeton pusillus	-2.5 to 0.8
Potamogeton richardsonii	-1.9 to -1.2
Potamogeton robbinsii	-1.6 to -1.3
Potamogeton rutilus	-1.6 to -1
Potamogeton spirillus	-1.6 to -1.3
Potamogeton trichoides	-1.6 to 0.8
Potamogeton vaseyi	-1.6 to -1.3
Proserpinaca palustris	-1.6 to -1.3
Pulicaria vulgaris	-1.3 to -0.7
Ranunculus aquatilis	-2.7 to -1
Ranunculus aquatilis var. diffusus	-1.6 to -1.3
Ranunculus circinatus	-1.6 to -1
Ranunculus lingua	-1.6 to -1
Ranunculus repens	-1.6 to -1
Ranunculus reptans	-1.6 to -1
Ranunculus revellieri	-1.3 to -0.7
Ranunculus sardous	-1.3 to -0.7
Ranunculus sceleratus	-1.6 to -1
Ranunculus trichophyllus	-2.5 to -1
Ricciella fluitans	-1.1 to -1
Rorippa amphibia	-1.6 to -1
Rorippa palustris	-1.6 to -1
Rumex hydrolapathum	-2 to -0.1
Rumex maritimus	-1.6 to -1
Sagina nodosa	-1.6 to -1
Sagittaria latifolia	-0.3 to 0.8
Sagittaria sagittifolia	-1.6 to -1
Schoenoplectus californicus	-1.9 to -0.9

Species	**^{10}log TP**
Schoenoplectus lacustris	-1.6 to -0.4
Schoenoplectus subterminalis	-1.8 to -0.5
Scirpus cyperinus	-1.6 to -0.5
Scirpus microcarpus	-0.3 to 0.8
Scirpus radicans	-1.6 to -1
Scolochloa festucacea	-1.6 to -1
Scutellaria galericulata	-1.6 to -1
Sium latifolium	-1.6 to -1
Sium suave	-2.5 to 0.8
Solanum dulcamara	-1.6 to -1
Sparganium americanum	-2.5 to -0.5
Sparganium angustifolium	-2.7 to -0.5
Sparganium emersum	-1.6 to -1
Sparganium erectum	-1.6 to -1
Sparganium eurycarpum	-0.3 to 0.8
Sparganium fluctuans	-2.5 to -0.5
Sphagnum denticulatum	-2.7 to -1.9
Spirodela polyrrhiza	-1.6 to -0.5
Stachys palustris	-1.6 to -1
Stellaria palustris	-1.6 to -1
Stratiotes aloides	-1.6 to -0.4
Stuckenia filiformis	-1.8 to -1
Stuckenia pectinata	-3 to -0.3
Subularia aquatica	-2.7 to -1.6
Symphytum officinale	-1.6 to -1
Thelypteris palustris	-1.6 to -1
Trapa natans	-1.6 to -0.7
Trapa natans var. bispinosa	-1.6 to -0.9
Trifolium michelianum	-1.3 to -0.7
Typha angustifolia	-1.6 to -0.7
Typha latifolia	-2.5 to 0.8
Utricularia geminiscapa	-1.6 to -1.3
Utricularia gibba	-1.6 to -1.3
Utricularia intermedia	-1.6 to -0.5
Utricularia minor	-2.5 to -0.5
Utricularia purpurea	-2.5 to -0.5
Utricularia radiata	-1.6 to -1.3

Species	**^{10}log TP**
Utricularia subulata	-1.6 to -1.3
Utricularia vulgaris	-2.5 to -0.5
Vallisneria americana	-3 to -1
Vallisneria spiralis	-1.9 to -0.7
Warnstorfia exannulata	-2.7 to -1.9
Zannichellia palustris	-1.6 to 0.2
(e) Non-silicon-based algae in lakes	
Cold	
Ankyra judayi	-2 to -0.2
Chlamydomonas nivalis	-1.6 to 0.5
Dinobryon divergens	-0.9 to -0.4
Dinobryon sociale	-0.9 to -0.4
Monoraphidium contortum	-1.5 to 0.5
Ochromonas ovalis	-1.6 to -0.4
Oocystis submarina	-2.3 to -1.1
Pediastrum integrum	-2.3 to -1.1
Pleurococcus antarcticus	-1.6 to -0.7
Prasiococcus calcarius	-2 to 0.5
Prasiola crispa	-1.7 to 0.5
Pseudoschroederia robusta	-2.2 to -1.4
Scenedesmus ellipticus	-2 to -1.1
Stichococcus bacillaris	-1.5 to 0.5
Tetraspora gelatinosa	-1.8 to -1.5
Tribonema utriculosum	-1.6 to -0.4
Ulothrix moniliformis	-2.7 to -0.2
Temperate	
Actinastrum gracillimum	-0.7 to 0
Actinastrum hantzschii	-0.7 to 0.2
Acutodesmus acuminatus	-0.7 to 1.2
Ankistrodesmus falcatus	-2.3 to 1.1
Ankistrodesmus gracilis	-1 to 0
Ankistrodesmus spiralis	-1.6 to -1.5
Bitrichia ollula	-2.7 to -2
Botryococcus braunii	-1.6 to -1
Carteria pseudoglobosa	-1.3 to -0.2

Appendix S5.2

Species	**^{10}log TP**
Chara contraria	-2 to -1.7
Chara globularis	-1.6 to -0.5
Chara vulgaris	-1.8 to -1.7
Chlamydomonas microsphaera	-1.3 to -0.2
Chlamydomonas reinhardtii	-1.3 to -0.2
Chlorella vulgaris	-1.8 to -1.6
Chlorococcum infusionum	-1.8 to -1.6
Chlorogonium elongatum	-1.3 to -0.2
Chloromonas angustissima	-2.7 to -2
Chromulina minor	-1.6 to -1.5
Chromulina nebulosa	-2.3 to -2
Chromulina parvula	-1.6 to -1.5
Chrysochromulina parva	-2.5 to -2
Chrysococcus rufescens	-2.3 to -2
Coelastrum astroideum	-1.4 to 1.2
Coelastrum microporum	-1.8 to 1.2
Cosmocladium constrictum	-2.2 to -2
Crucigenia tetrapedia	-1.7 to 1.2
Crucigeniella apiculata	-1 to 1.2
Crucigeniella rectangularis	-1.6 to -1
Cryptomonas curvata	-2.2 to 0.9
Cryptomonas erosa	-2.7 to 1.2
Cryptomonas gracilis	-2.5 to -2
Cryptomonas marssonii	-2.7 to 1.2
Cryptomonas ovata	-2 to -0.2
Dactylococcopsis fascicularis	-1.6 to -1.5
Desmodesmus intermedius	-0.5 to 0.9
Desmodesmus opoliensis	-0.7 to 0
Dinobryon bavaricum	-1.7 to 1.2
Dinobryon cylindricum	-2.5 to -2
Dinobryon sertularia	-1.6 to -0.2
Dinobryon stipitatum	-1.8 to -1.6
Elakatothrix gelatinosa	-2.3 to -0.2
Eudorina elegans	-2.2 to -0.2
Gonium pectorale	-1.3 to -0.6
Hariotina reticulata	-1.6 to 1.2
Katablepharis ovalis	-2.3 to -2
Kephyrion globosum	-1 to -0.4
Komma caudata	-1.6 to -0.7
Lagerheimia genevensis	-1.6 to -1
Mallomonas akrokomos	-2.4 to -2
Mallomonas caudata	-1.8 to -0.7
Mallomonas pseudocoronata	-1.8 to -1.6
Micractinium pusillum	-1.6 to -0.1
Monactinus simplex	-1.4 to 1.2
Monoraphidium dybowskii	-2.5 to -2.2
Monoraphidium komarkovae	-0.7 to 0
Monoraphidium minutum	-1.4 to -1
Monosiga ovata	-1.3 to -0.2
Mougeotia parvula	-1.6 to -1.5
Mucidosphaerium pulchellum	-1.8 to 1.1
Mychonastes minusculus	-2.3 to -2
Nitella flexilis	-1.8 to -1.6
Nitella mucronata	-1.5 to -1.3
Nitellopsis obtusa	-1.6 to -0.7
Ochromonas elegans	-1.6 to -1.5
Ochromonas minuscula	-1.6 to -1.5
Ochromonas ovalis	-1.6 to -1.5
Ochromonas verrucosa	-1.6 to -1.5
Oocystidium ovale	-2.3 to -2
Oocystis lacustris	-2.3 to 0.5
Oocystis parva	-2.3 to -1
Oocystis pusilla	-1.6 to -1.5
Ophiocytium capitatum	-1.6 to -1.5
Ophiocytium cochleare	-1.6 to -1.5
Ophiocytium parvulum	-1.6 to -1.5
Pandorina morum	-1.3 to 0
Pediastrum biwae	-2.2 to -2
Pediastrum duplex	-1.8 to 1.2
Pedinomonas minor	-1.6 to 1.2
Phacotus lenticularis	-1.2 to 1.2
Plagioselmis lacustris	-0.8 to 0.5
Plagioselmis nannoplanctica	-2.2 to -1.2
Planctonema lauterbornii	-1.6 to 0.2

Species	^{10}log TP
Planktosphaeria gelatinosa	-1.6 to -1
Pseudokephyrion entzii	-2.3 to -2
Pseudopediastrum boryanum	-1.8 to 1.2
Pteromonas angulosa	-0.4 to 0.2
Rhodomonas lacustris	-1.6 to -0.7
Rhodomonas lacustris var. nannoplanctica	-2.5 to 1.2
Rusalka fusiformis	-2.7 to -2.2
Scenedesmus abundans	-1.4 to -1
Scenedesmus arcuatus	-0.7 to 0
Scenedesmus ecornis	-1.4 to 1.1
Scenedesmus ellipticus	-1.4 to 0.2
Scenedesmus longispina	-1.6 to 1.2
Scenedesmus magnus	-1.4 to -1
Scenedesmus obliquus	-1.1 to 1.2
Scenedesmus quadricauda	-1.8 to 1.1
Scenedesmus smithii	-1.4 to 1.1
Schroederia setigera	-1.4 to 1.1
Siderocystopsis punctifera	-1.4 to -1
Sphaerocystis schroeteri	-2.2 to 1.2
Sphaeroeca volvox	-1.3 to -0.6
Synura echinulata	-2.7 to -2
Synura uvella	-1.3 to -0.2
Tetrachlorella alternans	-1.6 to -1
Tetrachlorella incerta	-2.3 to -2
Tetraedron minimum	-2.5 to 1.2
Tetraedron triangulare	-0.6 to 0.9
Tetrastrum staurogeniiforme	-1.4 to 0.9
Tetrastrum triangulare	-0.6 to 1.2
Trepomonas agilis	-1.3 to -0.2
Tribonema affine	-1.6 to -1.5
Ulothrix aequalis	-1.8 to -1.6
Uroglenopsis americana	-1.4 to -0.7
Willea vilhelmii	-1.4 to -0.7
(Sub)tropical	
Actinastrum aciculare	1 to 1.2
Ankistrodesmus falcatus	1 to 1.4
Campylomonas marssonii	-2.3 to -1
Chara longifolia	0.9 to 1.5
Chlorella vulgaris	1 to 1.5
Cladophora glomerata	1 to 1.5
Coelastrum pulchrum	-0.2 to -0.1
Cryptomonas brasiliensis	-2.3 to -1
Cryptomonas marssonii	-2.5 to -1.9
Elakatothrix gelatinosa	1.1 to 1.2
Hindakia tetrachotoma	-2.3 to -1
Hydrodictyon reticulatum	0.9 to 1.2
Korshikoviella michailovskoensis	1 to 1.2
Microspora aequabilis	0.9 to 1.2
Monactinus simplex	1 to 1.5
Monoraphidium arcuatum	-2.5 to -1.9
Monoraphidium griffithii	-2.5 to -1.9
Monoraphidium tortile	-2.5 to -1.9
Mougeotia scalaris	0.9 to 1.2
Mucidosphaerium pulchellum	-2.5 to -1.9
Mychonastes elegans	-2.3 to -1
Nephrocytium lunatum	-0.2 to -0.1
Nitella opaca	0.9 to 1.5
Pandorina morum	-0.2 to -0.1
Pannus microcystiformis	-2.3 to -0.7
Pediastrum leonensis	0.9 to 1.5
Scenedesmus annatus	1.1 to 1.5
Scenedesmus ecornis	-2.5 to -1.9
Scenedesmus quadricauda	-0.2 to -0.1
Spirogyra maxima	0.9 to 1.5
Spirotaenia condensata	1 to 1.2
Ulothrix lamellosa	1.1 to 1.5
Uronema acutum	0.9 to 1.1
Zygnema coeruleum	1 to 1.5
(f) Silicon-based algae	
Cold	
Achnanthes acares	-2.5 to -2.3
Achnanthes didyma	-2.5 to -1.1

Appendix S5.2

Species	^{10}log TP
Achnanthes germainii	-2.7 to 0.5
Achnanthes impexa	-2.5 to -2
Achnanthes kriegeri	-2.7 to -2.3
Achnanthes minutissima	-2.5 to -2
Achnanthes suchlandtii	-2.5 to -1.4
Achnanthidium biasolettianum	-2.7 to 0.5
Achnanthidium coarctatum	-2.7 to -1.2
Achnanthidium minutissimum	-2.5 to -1.1
Amphora duseni	-2.7 to -0.9
Amphora pediculus	-2.4 to -1.1
Asterionella formosa	-2.5 to -1.5
Aulacoseira alpigena	-2.7 to -1.9
Aulacoseira lirata	-2.7 to -2
Caloneis bacillum	-1.7 to -0.9
Cavinula pseudoscutiformis	-2.5 to -2
Closterium acutum	-2 to -1.1
Cosmarium laeve	-2.3 to -1.1
Cosmarium margaritiferum	-2 to -1.1
Cosmarium rectangulare	-2.4 to -2
Craticula halophila	-1.8 to -0.4
Craticula molesta	-2.7 to -2.3
Craticula molestiformis	-0.9 to -0.4
Cyclotella comensis	-2.5 to -2.1
Cyclotella meneghiniana	-1.5 to -0.9
Cyclotella pseudostelligera	-2.5 to -1.1
Diadesmis contenta	-2.2 to -0.4
Diatoma tenuis	-2.5 to -1.5
Encyonema lange-bertalotii	-2.7 to -1.9
Encyonema silesiacum	-2.5 to -1.1
Eolimna minima	-2.5 to -1.1
Eucocconeis quadratarea	-2.7 to -0.2
Eunotia bilunaris	-2.5 to -2.3
Eunotia exigua	-2.5 to -2.3
Eunotia glacialis	-2.5 to -2.3
Eunotia meisteri	-2.7 to -2.3
Eunotia muscicola	-2.7 to -2.5
Eunotia praerupta	-2.5 to -2
Fragilaria capucina	-2.7 to 0.5
Fragilaria tenera	-2.5 to -1.5
Fragilaria crotonensis	-2.5 to -1.2
Fragilariforma neoproducta	-2.3 to -2.2
Fragilariforma virescens	-2.5 to -1.9
Frustulia crassinervia	-2.7 to -2
Frustulia saxonica	-2.7 to -2.3
Gomphonema affine	-1.8 to -0.9
Gomphonema clavatum	-2.7 to 0.5
Gomphonema gracile	-1.8 to -1
Gomphonema olivaceum	-2.7 to -0.9
Gomphonema parvulum	-1.8 to -0.9
Hannaea arcus	-2.5 to -1.2
Hantzschia amphioxys	-2.7 to -0.4
Hippodonta capitata	-2 to -0.5
Hygropetra balfouriana	-2.5 to -1.9
Luticola mutica	-1.7 to -0.4
Luticola muticopsis	-2.7 to 0.5
Melosira italica	-2.5 to -1.2
Navicula cincta	-2 to -0.9
Navicula digitulus	-2.5 to -2
Navicula elginensis	-2.7 to -0.4
Navicula pseudosilicula	-2 to -1.5
Navicula schmassmannii	-2.5 to -2
Neidium binodis	-2.5 to -1.1
Nitzschia acicularis	-2.5 to -1.4
Nitzschia capitellata	-2.2 to 0.5
Nitzschia dissipata	-2.5 to -1.2
Nitzschia fonticola	-2.4 to -1.1
Nitzschia inconspicua	-2.7 to -0.4
Nitzschia palea	-2.7 to 0.5
Nitzschia perminuta	-2.7 to -1.9
Orthoseira roeseana	-2.7 to 0.5
Pinnularia biceps	-2.7 to -2.3
Pinnularia borealis	-2.7 to 0.5
Pinnularia krookii	-2.2 to 0.5
Pinnularia maior	-1.4 to -1.2

Species	^{10}log TP
Pinnularia mesolepta	-2.7 to -2
Pinnularia microstauron	-2.7 to 0.5
Pinnularia schoenfelderi	-1.5 to 0.5
Planothidium delicatulum	-2.7 to 0.5
Planothidium lanceolatum	-2.7 to 0.5
Psammothidium curtissimum	-2.7 to -1.9
Psammothidium helveticum	-2.7 to -1.9
Psammothidium lacusvulcani	-2.5 to -1.1
Psammothidium levanderi	-2.7 to -2
Psammothidium marginulatum	-2.7 to -2
Psammothidium subatomoides	-2.7 to 0.5
Pseudostaurosira brevistriata	-2.5 to -1.1
Pseudostaurosira brevistriata var. inflata	-2.3 to -1.1
Pseudostaurosira elliptica	-2 to -1.8
Pseudostaurosira parasitica	-2.5 to -1.1
Rhopalodia gibba	-2.5 to -1.1
Rossithidium pusillum	-2.5 to -1.2
Sellaphora bacillum	-1.7 to -1.5
Sellaphora seminulum	-2 to -1.9
Stauroneis anceps	-2.7 to 0.5
Stauroneis neohyalina	-2.7 to -2
Staurosira construens	-2.7 to -0.9
Staurosira construens var. exigua	-2.5 to -1.1
Staurosira venter	-2.5 to -1.1
Staurosirella lapponica	-2.5 to -1.1
Staurosirella pinnata	-2.5 to -1.1
Tabellaria flocculosa	-2.7 to -1.2
Temperate	
Achnanthes saccula	-2.7 to 1.3
Achnanthidium minutissimum	-3 to 1.6
Actinella parva	-2.7 to -1
Adlafia bryophila	-2.7 to -1
Amphora libyca	-2.7 to -1.2
Amphora pediculus	-2.2 to 1.3
Asterionella formosa	-2.7 to 1.6
Asterionella ralfsii	-2.7 to -1.5
Aulacoseira alpigena	-2.2 to -0.8
Aulacoseira ambigua	-2.7 to 1.6
Aulacoseira crenulata	-2.7 to -1.7
Aulacoseira distans	-3 to 1.6
Aulacoseira granulata	-2.2 to 1.1
Aulacoseira granulata var. angustissima	-2.7 to -1
Aulacoseira humilis	-2.3 to -1.5
Aulacoseira islandica	-2 to -0.7
Aulacoseira italica	-2.7 to 1.2
Aulacoseira lacustris	-3 to -2
Aulacoseira lirata	-2.3 to -1.5
Aulacoseira nivalis	-2.3 to -1.5
Aulacoseira perglabra	-3 to 1.3
Aulacoseira pfaffiana	-2.2 to -1.6
Aulacoseira subborealis	-2.7 to -1
Aulacoseira valida	-2.2 to -1.6
Aulacoseira voya	-1.9 to -1.8
Bacillaria paxillifera	-2.2 to -0.5
Brachysira brachysira	-2.7 to -1
Brachysira neoexilis	-2.7 to -1.5
Brachysira styriaca	-2.7 to -1
Brachysira vitrea	-2.7 to -1
Caloneis silicula	-2.2 to -1.5
Closterium aciculare	-2.2 to -1
Closterium acutum	-1.6 to 1.2
Closterium limneticum	-1.4 to -1
Cocconeis neodiminuta	-1.9 to -1.2
Cocconeis placentula	-2.7 to 0
Cocconeis placentula var. euglypta	-1.4 to -1.2
Cosmarium asphaerosporum	-2.3 to -2
Cosmarium phaseolus	-1.6 to -1.2
Ctenophora pulchella	-0.7 to 0
Cyclostephanos dubius	-2.7 to 0.9
Cyclostephanos invisitatus	-2.7 to -1
Cyclostephanos tholiformis	-2.7 to -0.8
Cyclotella atomus	-1.9 to 0.9
Cyclotella bodanica	-3 to 1.3

Appendix S5.2

Species	^{10}log TP
Cyclotella comensis	-2.7 to -0.6
Cyclotella comta	-2.2 to -0.4
Cyclotella cyclopuncta	-2.7 to -0.8
Cyclotella distinguenda	-2.7 to -0.8
Cyclotella gordonensis	-2.7 to -0.8
Cyclotella meneghiniana	-2.7 to 0.9
Cyclotella michiganiana	-2.7 to 1.1
Cyclotella ocellata	-2.4 to 1.2
Cyclotella planctonica	-2.7 to -1.2
Cyclotella pseudostelligera	-2.7 to 1.6
Cyclotella radiosa	-2.7 to -0.9
Cyclotella stelligeroides	-2.3 to -1.7
Cyclotella styriaca	-2.4 to -2.3
Cyclotella tasmanica	-2.7 to -1
Cyclotella tripartita	-2.2 to -1.1
Cyclotella wuethrichiana	-2.2 to -1.8
Cylindrotheca closterium	-1.4 to -1
Cymbella affinis	-2 to -1.2
Cymbella cistula	-2.7 to -1
Cymbella hebridica	-3 to -2
Cymbella helvetica	-2.2 to -1.5
Delicata delicatula	-2.2 to -1.7
Denticula tenuis	-2.1 to -1.7
Diadesmis contenta	-2.7 to -1
Diatoma hyemalis	-2.2 to -1.5
Diatoma mesodon	-2.7 to -1
Diatoma tenuis	-2.7 to -0.5
Diatoma vulgaris	-0.8 to 0
Diatomella balfouriana	-2.7 to -1
Diploneis ovalis	-2.2 to -1.5
Discostella glomerata	-2.1 to -1.7
Discostella stelligera	-2.7 to 0.9
Encyonema gaeumannii	-3 to -2
Encyonema gracile	-2.7 to -1
Encyonema mesianum	-2.7 to -1
Encyonema minutum	-2.7 to -1
Encyonema silesiacum	-3 to -1
Encyonopsis cesatii	-2.2 to -2.1
Encyonopsis microcephala	-2.7 to 0.7
Eolimna minima	-2.7 to 1.5
Epithemia adnata	-1.6 to -0.8
Epithemia sorex	-2.7 to -1
Eunotia arculus	-2.3 to -1.5
Eunotia bilunaris	-2.7 to -1.5
Eunotia exigua	-2.1 to -2
Eunotia flexuosa	-2.7 to -1.5
Eunotia incisa	-2.7 to -1
Eunotia mucophila	-3 to -2
Eunotia naegelii	-2.7 to -1
Eunotia pectinalis	-2.7 to -0.8
Fragilaria capucina	-2.7 to 0
Fragilaria capucina subsp. Rumpens	-2.7 to -1
Fragilaria capucina var. vaucheriae	-2.7 to -1
Fragilaria crotonensis	-2.7 to 1.1
Fragilaria nanana	-2.7 to -1
Fragilaria pseudoconstruens	-2.2 to -1.9
Fragilaria radians	-1.6 to -1.5
Fragilaria rhomboides	-2.3 to -1.5
Fragilaria tenera	-2.7 to -1
Fragilariforma exigua	-2.7 to -1
Fragilariforma virescens	-3 to 1.6
Frustulia rhomboides	-3 to -1
Frustulia vulgaris	-2.7 to -1
Gomphonema angustatum	-2.7 to -1
Gomphonema clavatum	-2.7 to -1
Gomphonema gracile	-2 to -1.6
Gomphonema lagenula	-2.7 to -1
Gomphonema parvulum	-2.7 to -1
Gomphonema pumilum	-2.7 to -1
Gomphonema truncatum	-2.2 to -1.5
Gyrosigma acuminatum	-1.4 to -0.8
Hantzschia amphioxys	-0.6 to -0.5
Karayevia clevei	-2.7 to -1
Karayevia oblongella	-2.7 to -1

Species	^{10}log TP
Martyana martyi	-2.7 to -1
Mastogloia smithii	-2.7 to -1
Mayamaea agrestis	-1.6 to 1.5
Melosira ambigua	-1.4 to 1.1
Melosira italica	-2.7 to 1.6
Melosira solida	-2.2 to -2
Melosira varians	-2.2 to -2
Meridion circulare	-3 to -1.5
Navicula capitatoradiata	-2.7 to -1
Navicula cryptocephala	-3 to 1.5
Navicula cryptotenella	-2.7 to -1
Navicula gottlandica	-2.7 to -1
Navicula gregaria	-2.7 to -1
Navicula heimansioides	-2.7 to -1
Navicula notha	-2.7 to -1
Navicula obsoleta	-2.7 to -1
Navicula radiosa	-2.7 to -0.5
Navicula rhynchocephala	-2.7 to 0
Navicula seminuloides	1.1 to 1.5
Navicula submuralis	-1.9 to 1.3
Navicula subtilissima	-3 to -1
Navicula trivialis	-2.2 to -1.5
Navicula veneta	-2.7 to -1
Navicula viridula	-1.4 to -1.2
Nitzschia acicularis	-2.7 to 0.9
Nitzschia acidoclinata	-2.7 to -1
Nitzschia agnita	-1.4 to -0.8
Nitzschia amphibia	-2.7 to -1
Nitzschia fonticola	0.7 to 1.6
Nitzschia graciliformis	-2.3 to -1.5
Nitzschia gracilis	-3 to -1
Nitzschia inconspicua	-2.7 to -1
Nitzschia lacuum	-2 to -1.7
Nitzschia liebetruthii	-2.7 to -1
Nitzschia linearis	-2.7 to -1
Nitzschia palea	-2.7 to 1.2
Nitzschia paleacea	-1.4 to -0.9
Nitzschia perminuta	-2.7 to -1
Nitzschia pura	-2.7 to -1.7
Nitzschia recta	-2.7 to -1
Nitzschia sigma	-1.6 to -1
Nitzschia subacicularis	-2.7 to -1
Nitzschia tropica	-2.7 to -1
Pinnularia appendiculata	-2.2 to -2.1
Pinnularia maior	-2.2 to -1.5
Pinnularia microcephala	-2.3 to -1.5
Pinnularia microstauron	-3 to -2
Pinnularia subrostrata	-1.4 to -1.2
Pinnularia sudetica	-2.2 to -1.5
Planothidium frequentissimum	-2.7 to -1
Planothidium hauckianum	-2.1 to -1.6
Planothidium lanceolatum	-2.7 to 1.1
Planothidium lemmermannii	-1.9 to -1.7
Psammothidium levanderi	-2.7 to -1
Psammothidium subatomoides	-2.7 to -1
Pseudostaurosira brevistriata	-3 to 1.3
Pseudostaurosira brevistriata var. inflata	-2.7 to -1
Pseudostaurosira elliptica	-2.7 to -1
Pseudostaurosira parasitica	-2.7 to -1
Puncticulata bodanica	-1.5 to -0.9
Rhizosolenia longiseta	-1.4 to -0.7
Rhoicosphenia abbreviata	-2.7 to -1
Rhopalodia gibba	-1.8 to -1.2
Rhopalodia novae-zelandiae	-2.7 to -1
Rossithidium pusillum	-2.7 to -1
Sellaphora pupula	-2.7 to 1.6
Sellaphora seminulum	-2.7 to 1.5
Spondylosium moniliforme	-2.2 to -2
Spondylosium planum	-0.7 to -0.1
Staurastrum arctiscon	-2.2 to -2
Staurastrum dorsidentiferum	-2.2 to -2
Staurastrum limneticum	-2.2 to -2
Staurastrum manfeldtii	-1.1 to 1.2
Staurastrum sebaldii	-0.7 to 0

Appendix S5.2

Species	^{10}log TP
Staurastrum tetracerum	-1.4 to -1
Staurodesmus incus	-2.5 to -2
Staurodesmus megacanthus	-2.1 to -2
Stauroneis anceps	-2.3 to -1.5
Staurosira construens	-2.7 to 1.6
Staurosira construens f. venter	-2.7 to -1
Staurosira construens var. binodis	-2.7 to -1
Staurosira construens var. exigua	-2.3 to -1.5
Staurosirella construens	-1.4 to 1.3
Staurosirella leptostauron	-2.7 to -1
Staurosirella pinnata	-3 to 1.3
Stephanodiscus alpinus	-2.7 to -0.9
Stephanodiscus carconensis	-2.2 to -2
Stephanodiscus complex	-2.7 to -1.6
Stephanodiscus hantzschii	-2.2 to 1.3
Stephanodiscus medius	-2.2 to -0.9
Stephanodiscus minutulus	-2.3 to 1.3
Stephanodiscus neoastraea	-2 to -0.9
Stephanodiscus niagarae	-2.2 to 1.6
Stephanodiscus parvus	-2.7 to -0.7
Surirella linearis var. constricta	-2.7 to -1
Synedra nana	-2.7 to -1.6
Synedra ulna	-2.7 to -0.1
Synedra utermohlii	-0.7 to 0
Tabellaria fenestrata	-3 to 1.2
Tabellaria flocculosa	-3 to 1.2
Thalassiosira pseudonana	-0.5 to 0.2
Ulnaria acus	-2.7 to 1.2
Ulnaria delicatissima	-2.3 to -0.9
Ulnaria ulna	-2.2 to 1.6
Urosolenia eriensis	-2.7 to 0.9
Xanthidium antilopaeum	-2.2 to -2
Xanthidium hastiferum	-2.2 to -2
Xeric	
Achnanthes exigua	-2 to -0.7
Achnanthes saccula	-2 to -0.4

Species	^{10}log TP
Amphora inariensis	-2 to -1.2
Amphora libyca	-2 to 0.1
Amphora perpusilla	-2 to 0.1
Anomoeoneis sphaerophora	-2 to 0.1
Caloneis bacillum	-1.7 to 0.1
Cocconeis placentula	-2 to 0.1
Cocconeis placentula var. baikalensis	-1.5 to 0.1
Cocconeis placentula var. euglypta	-2 to 0.1
Cyclotella ocellata	-2 to -0.4
Cyclotella radiosa	-2 to 0.1
Cymbella neoleptoceros	-1.6 to -0.4
Denticula kuetzingii	-2 to -0.4
Encyonema minutum	-1.6 to 0.1
Encyonopsis cesatii	-1.6 to -0.4
Fragilaria capucina	-1.7 to -0.4
Fragilaria tenera	-2 to 0.1
Fragilariforma virescens	-1.5 to 0.1
Gyrosigma acuminatum	-1.8 to -1.5
Halamphora thumensis	-2 to -0.4
Hippodonta capitata	-1.6 to 0.1
Hippodonta hungarica	-1.7 to -0.4
Martyana martyi	-1.5 to 0.1
Navicula cryptocephala	-1.5 to 0.1
Navicula cryptotenella	-2 to 0.1
Navicula eidrigiana	-1.7 to -0.4
Navicula upsaliensis	-1.7 to 0.1
Navicula veneta	-1.7 to 0.1
Nitzschia bacillum	-2 to 0.1
Nitzschia frustulum	-1.7 to 0.1
Nitzschia lacuum	-2 to 0.1
Nitzschia palea	-1.6 to -0.4
Nitzschia sublinearis	-1.6 to -0.4
Parlibellus cruciculus	-1.6 to 0.1
Planothidium lanceolatum	-1.7 to -0.4
Pseudostaurosira elliptica	-2 to 0.1
Pseudostaurosira pseudoconstruens	-2 to -0.8
Rhoicosphenia abbreviata	-2 to 0.1

Species	^{10}log TP
Stauroneis obtusa	-2 to -0.7
Staurosira brevistriata	-2 to -0.8
Staurosira construens	-2 to 0.1
Staurosira construens f. venter	-2 to -1.2
Staurosirella leptostauron	-2 to 0.1
Staurosirella pinnata	-2 to -0.8
Stephanodiscus minutulus	-2 to -0.8
Surirella peisonis	-1.6 to 0.1
Tryblionella apiculata	-2 to 0.1
(Sub)tropical	
Achnanthidium minutissimum	-0.2 to 0.9
Asterionella formosa	0.9 to 1.1
Aulacoseira ambigua	-2.5 to -1.9
Aulacoseira distans	-2.5 to -1.9
Aulacoseira granulata	-2.5 to 0.9
Closterium acerosum	1.3 to 1.5
Closterium acutum	-2.3 to -1
Closterium depressum	1.2 to 1.5
Closterium dianae	1.2 to 1.5
Closterium lineatum	1.2 to 1.5
Closterium sphaerosporum	1 to 1.5
Cocconeis neodiminuta	1 to 1.2
Diatoma vulgaris	0.9 to 1.5
Fragilaria capucina	0.1 to 0.9
Fragilariopsis oceanica	0.9 to 1.5
Frustulia rhomboides	0.9 to 1.5
Gomphonema acuminatum	0.9 to 1.2
Meuniera membranacea	0.9 to 1.5
Nitzschia bilobata	1 to 1.5
Nitzschia palea	-2.5 to -1.9
Pinnularia viridis	0.9 to 1.2
Tabellaria fenestrata	1 to 1.5
Ulnaria capitata	0.9 to 1
Urosolenia eriensis	-2.5 to -1.9
Urosolenia longiseta	-2.5 to -1.9

Species	^{10}log TP
(g) Cyanobacteria in streams	
Temperate	
Chroococcus dispersus	-1.2 to -0.9
Dolichospermum flosaquae	-1.2 to -0.2
Jaaginema angustissimum	-1.2 to -0.2
Leptolyngbya tenuis	0 to 0.2
Limnococcus limneticus	-0.7 to -0.1
Microcystis aeruginosa	-1.2 to -0.4
Microcystis ichthyoblabe	-1.1 to -0.2
Microcystis pulverea	-1.2 to -0.4
Oscillatoria limosa	-1.2 to -0.3
(Sub)tropical	
Anabaena solitaria	-1.8 to -1.2
Aphanocapsa delicatissima	-1.3 to -0.7
Aphanocapsa holsatica	-1.3 to -1
Aphanothece stagnina	-1.2 to -0.8
Calothrix epiphytica	-1.3 to -0.8
Calothrix stagnalis	-1.3 to -1
Chroococcus minutus	-1.3 to -0.7
Chroococcus turgidus	-3 to -0.7
Coelosphaerium kuetzingianum	-1.3 to -1
Cylindrospermopsis raciborskii	-1.8 to -1.2
Dolichospermum affine	-1.8 to -1.2
Dolichospermum spiroides	-1.8 to -1.2
Geitlerinema splendidum	-3 to -1
Leptochaete stagnalis	-1.3 to -0.8
Leptolyngbya boryana	-1.3 to -1
Leptolyngbya lagerheimii	-1.2 to -0.8
Leptolyngbya subtilis	-1.3 to -0.8
Leptolyngbya tenuis	-1.3 to -0.8
Limnococcus limneticus	-3 to -0.7
Lyngbya birgei	-1.2 to -0.8
Lyngbya major	-3 to -1
Lyngbya martensiana	-1.8 to -1.2
Merismopedia elegans	-1.3 to -0.8
Merismopedia glauca	-1.8 to -1.2

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Species	^{10}log TP
Merismopedia tenuissima	-1.8 to -0.8
Microcystis aeruginosa	-1.8 to -0.7
Microcystis protocystis	-3 to -1
Oscillatoria anguina	-1.3 to -1
Oscillatoria sancta	-1.8 to -1.2
Phormidium willei	-3 to -1
Planktolyngbya contorta	-1.3 to -0.8
Planktolyngbya limnetica	-1.8 to -1
Pseudanabaena galeata	-1.3 to -0.7
Pseudanabaena limnetica	-1.2 to -0.8
Pseudanabaena mucicola	-3 to -1
Raphidiopsis mediterranea	-1.8 to -1.2
Snowella lacustris	-1.3 to -1
(h) Fish in streams	
Cold	
Salmo trutta	-2 to -1.4
Temperate	
Ambloplites rupestris	-1.2 to -0.4
Ameiurus melas	-1.4 to 0.5
Ameiurus natalis	-1.4 to 0.5
Anguilla rostrata	-1 to -0.6
Aphanius iberus	-2 to -1.6
Aphredoderus sayanus	-1 to -0.6
Campostoma anomalum	-1.4 to 0.5
Campostoma oligolepis	-1.7 to -0.4
Carpiodes cyprinus	-1.4 to 0.5
Catostomus commersonii	-1.4 to 0.5
Cottus bairdii	-1.4 to 0.5
Culaea inconstans	-1.4 to 0.5
Cyprinella whipplei	-1.4 to 0.5
Cyprinus carpio	-1.4 to 0.5
Erimyzon oblongus	-1 to -0.6
Esox americanus	-1.4 to 0.5
Etheostoma blennioides	-1.4 to 0.5
Etheostoma caeruleum	-1.4 to 0.5

Species	^{10}log TP
Etheostoma nigrum	-1.4 to 0.5
Etheostoma olmstedi	-1 to -0.6
Etheostoma simoterum	-1.2 to -0.4
Etheostoma spectabile	-1.4 to 0.5
Gambusia affinis	-1.4 to 0.5
Hypentelium nigricans	-1.4 to 0.5
Ictalurus punctatus	-1.4 to 0.5
Lepomis auritus	-1.2 to -0.4
Lepomis cyanellus	-1.4 to 0.5
Lepomis gibbosus	-1.4 to 0.5
Lepomis macrochirus	-1.4 to 0.5
Lepomis megalotis	-1.4 to 0.5
Lepomis microlophus	-1.4 to 0.5
Luxilus chrysocephalus	-1.4 to 0.5
Luxilus cornutus	-1.4 to 0.5
Micropterus salmoides	-1.4 to 0.5
Nocomis biguttatus	-1.4 to 0.5
Nocomis leptocephalus	-1 to -0.6
Notemigonus crysoleucas	-1.4 to 0.5
Notropis albeolus	-1 to -0.6
Notropis buccatus	-1.4 to 0.5
Notropis procne	-1 to -0.6
Percina maculata	-1.4 to 0.5
Pimephales notatus	-1.4 to 0.5
Pimephales promelas	-1.4 to 0.5
Rhinichthys atratulus	-1.4 to 0.5
Rhinichthys obtusus	-1.2 to -0.4
Semotilus atromaculatus	-1.4 to 0.5
Umbra limi	-1.4 to 0.5
(i) Invertebrates in streams	
Cold	
Lymnaea peregra	-1.8 to -1.4
Temperate	
Ablabesmyia longistyla	-1.3 to 0.2
Ablabesmyia monilis	-1.5 to 0.5

Species	^{10}log TP
Ablabesmyia phatta	-1.3 to -0.4
Acentrella insignificans	-1.7 to 0
Acerpenna pygmaea	-1.9 to -1.8
Acilius canaliculatus	-1.2 to -0.6
Acricotopus lucens	-1.5 to 0.3
Acroloxus lacustris	-1.3 to 0.2
Acroneuria abnormis	-1.8 to -1.7
Adicella reducta	-1.2 to -0.6
Aeshna cyanea	-2 to 0.3
Aeshna mixta	-1.5 to -0.5
Agabus bipustulatus	-1.7 to 0.2
Agabus chalconatus	-1.3 to 0.2
Agabus didymus	-2 to 0.1
Agabus guttatus	-0.8 to -0.6
Agabus paludosus	-1.7 to -0.2
Agabus sturmii	-1.5 to 0.6
Agabus undulatus	-1.4 to 0.1
Agapetus fuscipes	-1.7 to -0.5
Agnetina capitata	-1.6 to -1.5
Agraylea multipunctata	-1.3 to -0.3
Agraylea sexmaculata	-1.3 to -0.6
Agrypnia pagetana	-1.3 to -0.4
Amphichorema zotheculum	-2.2 to -1.4
Amphinemura banksi	-1.7 to -0.1
Anabolia nervosa	-1.7 to 0.6
Anacaena bipustulata	-1.3 to -0.5
Anacaena globulus	-1.5 to 0.9
Anacaena limbata	-1.5 to 0.5
Anacaena lutescens	-1.5 to -0.1
Anatopynia plumipes	-0.5 to 1
Anax imperator	-1.4 to -1.3
Ancylus fluviatilis	-1.3 to 0.4
Andesiops torrents	-2 to -1
Andogyrus seriatopunctatus	-2.2 to -0.9
Anisus leucostoma	-1.3 to 0.6
Anisus spirorbis	-1 to 0.5
Anisus vortex	-2 to 0.6
Anisus vorticulus	-1.5 to 0.1
Anodonta anatina	-1.3 to -0.1
Anopheles messeae	-1.3 to -0.6
Antarctoperla michaelseni	-2.2 to -0.9
Aplexa hypnorum	-1.3 to 0.1
Apsectrotanypus trifascipennis	-1.5 to 1.2
Aquarius najas	-1.2 to -0.4
Aquarius paludulum	-1.3 to -0.6
Arctopsyche grandis	-1.7 to -0.1
Argyroneta aquatica	-1.3 to 0.3
Arrenurus albator	-1.4 to 0.2
Arrenurus bifidicodulus	-0.7 to -0.5
Arrenurus buccinator	-1.5 to -0.2
Arrenurus crassicaudatus	-1.5 to -0.1
Arrenurus cylindratus	-1.5 to -0.3
Arrenurus globator	-2 to 0.2
Arrenurus knauthei	-1.2 to -0.7
Arrenurus latus	-1.3 to -0.6
Arrenurus leuckarti	-1.2 to -1
Arrenurus securiformis	-1.4 to -1
Arrenurus sinuator	-1.3 to -0.2
Arrenurus zachariae	-1 to -0.9
Ascomorpha ecaudis	-1.1 to 0.6
Asellus aquaticus	-1.8 to 1.2
Asplanchna brightwellii	-1.1 to 0.6
Atherix ibis	-0.8 to -0.1
Atherix pachypus	-1.7 to -0.1
Athripsodes aterrimus	-2 to 0.5
Athripsodes cinereus	-1.2 to 0
Atyaephyra desmaresti	-1.3 to -0.1
Aubertoperla illiesi	-2.2 to -1.4
Baetis bicaudatus	-1.7 to 0.2
Baetis brunneicolor	-1.5 to -1.4
Baetis intercalaris	-1.3 to -1.2
Baetis rhodani	-1.3 to 0.1
Baetis scambus	-0.9 to -0.1
Baetis tricaudatus	-1.7 to 0.7

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Species	^{10}log TP
Baetis vernus	-1.7 to 0.8
Bandakia concreta	-1 to -0.7
Bathyomphalus contortus	-1.4 to 0.6
Bdellocephala punctata	-0.9 to -0.5
Beauchampiella eudactylota	-1.1 to 0.6
Beraea maurus	-1.7 to -0.7
Beraea pullata	-1.4 to -0.2
Beraeodes minutus	-1.3 to 0.1
Bidessus unistriatus	-1.5 to 0.2
Bithynia leachi	-2 to 0.3
Bithynia leachii	-1.8 to -0.8
Bithynia tentaculata	-2 to 0.7
Boophthora erythrocephala	-1.5 to 0.2
Boyeria vinosa	-1 to -0.6
Brachionus ahlstromi	-1.1 to 0.6
Brachionus angularis	-1.1 to 0.6
Brachionus austrogenitus	-1.1 to 0.6
Brachionus bidentata	-1.1 to 0.6
Brachionus budapestinensis	-1.1 to 0.6
Brachionus calyciflorus	-1.1 to 0.6
Brachionus caudatus	-1.1 to 0.6
Brachionus havanaensis	-1.1 to 0.6
Brachionus plicatilis	-1.1 to 0.6
Brachionus quadridentatus	-1.1 to 0.6
Brachionus rubens	-1.1 to 0.6
Brachionus urceolaris	-0.4 to 0.6
Brachycentrus americanus	-1.7 to -0.1
Brachycentrus appalachia	-1.7 to -1.6
Brachycentrus occidentalis	-1.7 to -0.1
Brachypoda versicolor	-2 to -0.2
Brachysetodes major	-2.2 to -0.9
Branchiodrilus hortensis	-1.3 to -0.3
Branchiura sowerbyi	-1.3 to -0.1
Brillia flavifrons	-1.3 to 0.5
Brillia modesta	-1.7 to 0.1
Caenis horaria	-2 to 0.6
Caenis luctuosa	-1.3 to 0
Caenis robusta	-1.3 to 0.5
Callicorixa praeusta	-1.3 to 1.2
Calopteryx splendens	-1.3 to 0
Calopteryx virgo	-1.5 to 0
Cataclysta lemnata	-2 to 0.1
Centroptilum luteolum	-1.3 to -0.4
Centroptilum pennulatum	-1.3 to -1.2
Cephalodella catellina	-1.1 to 0.6
Cercyon convexiusculus	-1.3 to -1.2
Chaetarthria seminulum	-1.3 to 0.3
Chaetopteryx villosa	-1.7 to -0.5
Chaoborus crystallinus	-1.4 to 0.1
Chaoborus flavicans	-1.3 to -0.5
Chilenoperla semitincta	-2.2 to -1.4
Chilina patagonica	-2 to -1
Chiloporter penai	-1.7 to -1
Chimarra aterrima	-1.6 to -1.5
Chimarra obscura	-1.4 to -1.3
Chimarra socia	-1.8 to -1.7
Chimarra utahensis	-1.7 to -0.1
Chironomus bernensis	-1.4 to -0.1
Chironomus commutatus	-1.3 to -0.2
Chironomus luridus	-1.7 to -0.7
Chironomus nuditarsus	-1.3 to -0.2
Chironomus nudiventris	-1.3 to -0.2
Chironomus obtusidens	-1.3 to -0.7
Chironomus plumosus	-0.5 to -0.4
Chironomus riparius	-1.7 to -0.7
Chrysops caecutiens	-1.3 to -0.9
Cladotanytarsus mancus	-1.3 to -0.6
Clinotanypus nervosus	-1.7 to 0.2
Cloeon dipterum	-2 to 0.6
Cloeon simile	-1.4 to 0.1
Cnetha costata	-1.7 to -0.7
Cnetha latipes	-1.7 to -0.5
Coelostoma orbiculare	-1.2 to 0.1
Coenagrion puella	-0.9 to 0.6

Species	^{10}log TP
Coenagrion pulchellum	-1.3 to 0.2
Colurella colurus	-1.1 to 0.6
Colymbetes fuscus	-1.3 to 0.6
Conchapelopia melanops	-1.7 to 0.5
Conochilus coenobasis	-1.1 to 0.6
Conochilus unicornis	-1.1 to 0.6
Copelatus haemorrhoidalis	-0.9 to -0.6
Coquillettidia richardii	-1.5 to -1.3
Corbicula fluminalis	-1.3 to -0.2
Corbicula fluminea	-1.3 to -0.1
Corixa affinis	-1.5 to 1
Corixa dentipes	-1.3 to 0.3
Corixa punctata	-2 to 1
Corophium curvispinum	-1.3 to -0.1
Corydalus cornutus	-1.6 to -1.5
Corynoneura lobata	-1.1 to -0.4
Corynoneura scutellata	-1.3 to -0.7
Crangonyx pseudogracilis	-1.8 to -0.3
Crenobia alpina	-1.7 to -0.7
Cricotopus bicinctus	-1.7 to 0.7
Cricotopus intersectus	-1.3 to -0.7
Cricotopus sylvestris	-1.7 to 0.7
Cricotopus tremulus	-1.2 to -1
Cricotopus trifascia	-1.7 to 0.7
Cricotopus trifasciatus	-0.8 to -0.1
Cricotopus vierriensis	-1.3 to -1.2
Crunoecia irrorata	-1.7 to -0.7
Cryptochironomus defectus	-1.3 to -0.3
Cryptochironomus fulvus	-1.4 to -0.6
Cryptotendipes usmaensis	-1.3 to -0.5
Culex pipiens	-1.3 to 0.3
Culiseta annulata	-1.3 to 0.3
Cymatia coleoptrata	-1.2 to 0.2
Cymbiodyta marginella	-1.3 to -1
Cyrnus flavidus	-1.7 to 0.2
Cyrnus trimaculatus	-1.3 to 0.3
Dendrocoelum lacteum	-1.7 to 0.6

Species	^{10}log TP
Dero digitata	-1.3 to 0.3
Dero dorsalis	-1.3 to 0.3
Deuterophlebia coloradensis	-1.7 to -0.1
Dicranophoroides caudatus	-0.4 to 0.6
Dicranophorus halbachi	-0.4 to 0.6
Dicranophorus robustus	-0.4 to 0.6
Dicranota bimaculata	-1.7 to 0.1
Dicrotendipes neomodestus	-1 to -0.8
Dicrotendipes nervosus	-1.3 to -0.1
Dicrotendipes notatus	-1.5 to -0.2
Dikerogammarus villosus	-1.3 to -0.1
Dina lineata	-1.2 to -0.7
Diplocladius cultriger	-1.7 to 0.2
Diplodontus scapularis	-1.3 to -0.4
Dixa dilatata	-1.2 to -1.1
Dixa maculata	-1.7 to -0.8
Dixella filicornis	-1.3 to -1.2
Dreissena polymorpha	-1.8 to -0.1
Drunella coloradensis	-1.7 to -0.1
Drunella cornutella	-1.7 to -1.6
Drunella doddsi	-1.7 to -0.1
Drunella walkeri	-0.8 to 0
Dryops luridus	-1.5 to 0.1
Dubiraphia vittata	-1 to -0.6
Dugesia gonocephala	-1.2 to -0.8
Dugesia lugubris	-2 to 0.2
Dugesia polychroa	-1.3 to 0.2
Dugesia tigrina	-1.8 to -0.2
Dytiscus marginalis	-1.1 to 0.1
Echinogammarus berilloni	-1.3 to -0.8
Ecnomus tenellus	-1.3 to -0.1
Ectopria nervosa	-1 to -0.8
Einfeldia dissidens	-1.3 to -0.7
Einfeldia pagana	-1 to -0.2
Eiseniella tetraedra	-1.7 to 0.2
Elmis aenea	-1.5 to -0.1
Elmis maugetii	-0.9 to -0.8

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Species	^{10}log TP
Elodes minuta	-1.7 to -0.4
Elophila nymphaeata	-1.1 to -0.2
Enallagma cyathigerum	0.1 to 0.6
Endochironomus albipennis	-1.4 to 0.2
Endochironomus dispar	-0.9 to -0.1
Endochironomus tendens	-1.4 to 0.2
Enochrus affinis	-0.8 to -0.7
Enochrus melanocephalus	-1.2 to -0.7
Enochrus testaceus	-1.3 to 0.1
Enoicyla pusilla	-0.8 to -0.5
Epeorus albertae	-1.7 to -0.1
Epeorus deceptivus	-1.7 to -0.1
Epeorus longimanus	-1.7 to -0.1
Ephemera danica	-1.7 to -0.1
Ephemera vulgata	-0.8 to -0.2
Ephemerella ignita	-0.9 to 0
Ephemerella inermis	-1.7 to -0.1
Ephemerella subvaria	-1.5 to -1.4
Ephoron leukon	-1.7 to -1.6
Epiphanes clavatula	-1.1 to 0.6
Erpobdella nigricollis	-1.3 to -1
Erpobdella octoculata	-2 to 0.8
Erpobdella punctata	-1.5 to 0.7
Erpobdella testacea	-2 to 0.6
Erpobdella vilnensis	-0.9 to -0.2
Erythromma najas	-1.3 to 0.2
Euchlanis dilatata	-1.1 to 0.6
Eukiefferiella brevicalcar	-1.7 to -1
Eukiefferiella calvescens	-1.3 to -0.6
Eukiefferiella claripennis	-1.4 to -0.1
Eukiefferiella discoloripes	-1.3 to -0.6
Eusimulium angustipes	-1.3 to -0.5
Eusimulium aureum	-1.3 to 0.1
Euthyas truncata	-1.2 to -0.8
Eylais extendens	-1.4 to 0.2
Eylais hamata	-1.5 to -0.1
Eylais setosa	-1.4 to 0.2
Ferrissia walkeri	-1.8 to -0.4
Filinia opoliensis	-1.1 to 0.6
Forelia liliacea	-1 to -0.2
Forelia variegator	-1.3 to -0.2
Galba truncatula	-1.7 to 0.2
Gammarus fossarum	-1.7 to 0
Gammarus pulex	-2 to 0.6
Gammarus roeseli	-1 to -0.2
Gammarus roeselii	-1.5 to 0
Gammarus tigrinus	-1.8 to 0
Gerris argentatus	-1.3 to -0.6
Gerris gibbifer	-2 to -0.7
Gerris lacustris	-2 to 0.9
Gerris odontogaster	-1.4 to -0.1
Gerris thoracicus	-1.5 to 0
Glossiphonia complanata	-2 to 0.6
Glossiphonia heteroclita	-2 to 0.6
Glyphotaelius pellucidus	-1.7 to -0.5
Glyptotendipes barbipes	-1.5 to -0.4
Glyptotendipes pallens	-2 to -0.2
Glyptotendipes paripes	-1 to -0.7
Goera pilosa	-1.2 to -0.2
Goniobasis livescens	-0.8 to -0.3
Graptodytes pictus	-2 to 0.6
Guttipelopia guttipennis	-1.3 to -0.6
Gyraulus albus	-1.8 to 0.6
Gyraulus crista	-1.3 to 0.2
Gyraulus laevis	-0.8 to 0.1
Gyraulus riparius	-1.3 to 0.2
Gyrinus marinus	-2 to 0.3
Gyrinus substriatus	-2 to 0
Habrophlebia fusca	-1 to -0.4
Haementeria costata	-0.5 to -0.1
Haemopis sanguisuga	-1.4 to 0.4
Halesus radiatus	-1.7 to -0.3
Haliplus flavicollis	-1.5 to 0.6
Haliplus fluviatilis	-1.5 to 0.6

Species	^{10}log TP
Haliplus fulvus	-0.9 to 0.6
Haliplus heydeni	-2 to 0.5
Haliplus immaculatus	-2 to 0.6
Haliplus laminatus	-2 to 0.5
Haliplus lineatocollis	-2 to 0.6
Haliplus lineolatus	-1.1 to 0.2
Haliplus obliquus	-1.5 to -0.5
Haliplus ruficollis	-2 to 0.2
Haliplus wehnckei	-2 to 0.2
Harnischia curtilamellata	-1.3 to -0.4
Hebrus ruficeps	-1.3 to -0.9
Helicopsyche borealis	-1.7 to -0.1
Helobdella stagnalis	-2 to 1.2
Helochares lividus	-1.5 to 0.1
Helochares punctatus	-1.4 to 0.1
Helophorus aequalis	-1.4 to 0.9
Helophorus aquaticus	-1.3 to 0.3
Helophorus brevipalpis	-1.4 to 0.7
Helophorus flavipes	-1.7 to 0.6
Helophorus grandis	-1.3 to -0.3
Helophorus minutus	-2 to 0.3
Helophorus obscurus	-1.3 to 0.3
Helophorus strigifrons	-1.4 to -0.9
Hemiclepsis marginata	-1.5 to 0.2
Hemiosus dejeanii	-2.2 to -0.9
Hesperocorixa castanea	-0.8 to 0.3
Hesperocorixa linnaei	-1.2 to 0.5
Hesperocorixa sahlbergi	-1.4 to 0.6
Hesperoperla pacifica	-1.7 to -0.1
Heterotanytarsus apicalis	-1.5 to -0.5
Heterotrissocladius marcidus	-1.7 to 0
Hexarthra intermedia	-1.1 to 0.6
Hexarthra mira	-1.1 to 0.6
Hippeutis complanatus	-1.4 to 0.6
Holocentropus dubius	-1.3 to -0.2
Holocentropus picicornis	-1.3 to 0.6
Hyalella azteca	-1.5 to 0
Hyalella curvispina	-1.8 to -1.3
Hydora annectens	-2.2 to -1.2
Hydrachna cruenta	-1.5 to -0.2
Hydraena assimilis	-1 to -0.9
Hydraena riparia	-1.3 to -1.2
Hydraena testacea	-1.3 to 0.2
Hydrobius fuscipes	-1.5 to 0.7
Hydrochara caraboides	-1.4 to -1.2
Hydrochus angustatus	-1.3 to -0.4
Hydrochus carinatus	-0.9 to -0.7
Hydrodroma despiciens	-1.4 to 0.3
Hydrodroma torrenticola	-0.8 to -0.6
Hydroglyphus geminus	-1.3 to -0.6
Hydrometra stagnorum	-1.7 to 0.6
Hydromyza livens	-1.3 to -0.1
Hydrophilus piceus	-0.2 to 0.6
Hydroporus angustatus	-1.3 to -0.5
Hydroporus discretus	-1.3 to -0.6
Hydroporus erythrocephalus	-2 to -0.2
Hydroporus gyllenhalii	-1.4 to -0.5
Hydroporus incognitus	-1.4 to -0.3
Hydroporus memnonius	-1.5 to -0.5
Hydroporus nigrita	-1.3 to -1.2
Hydroporus palustris	-2 to 1
Hydroporus planus	-1.7 to 0.4
Hydropsyche angustipennis	-1.7 to 0.4
Hydropsyche betteni	-1.2 to -0.6
Hydropsyche instabilis	-0.5 to -0.2
Hydropsyche morosa	-1.5 to -1.4
Hydropsyche pellucidula	-1.2 to 0
Hydropsyche saxonica	-1.2 to 0
Hydropsyche scalaris	-1.5 to -1.4
Hydropsyche siltalai	-0.8 to -0.3
Hydropsyche slossonae	-1.3 to -1.2
Hydropsyche sparna	-1.2 to -1
Hydroptila spatulata	-1 to -0.8
Hydryphantes ruber	-1.3 to 0.2

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Species	^{10}log TP
Hygrobates fluviatilis	-1.3 to -0.6
Hygrobates longipalpis	-1.7 to -0.1
Hygrobates nigromaculatus	-1.7 to 0.2
Hygrobates trigonicus	-1.2 to -0.4
Hygrobia hermanni	-2 to 0
Hygrotus decoratus	-2 to -0.3
Hygrotus inaequalis	-1.5 to 0.7
Hygrotus versicolor	-1.5 to 0.6
Hyphydrus ovatus	-2 to 0.6
Ilybius fenestratus	-1.3 to -0.1
Ilybius fuliginosus	-1.7 to 0.2
Ilybius quadriguttatus	-1.2 to -0.5
Ilyodrilus templetoni	-1.3 to 0.1
Ironoquia dubia	-1.3 to -1
Ischnura elegans	-1.5 to 0.5
Isonychia bicolor	-1.6 to -1.5
Keratella americana	-1.1 to 0.6
Keratella cochlearis	-1.1 to 0.6
Keratella lenzi	-1.1 to 0.6
Keratella tropica	-1.1 to 0.6
Kiefferulus tendipediformis	-1.3 to 0.6
Klapopteryx kuscheli	-2.2 to -1.4
Laccobius bipunctatus	-1.5 to 0.7
Laccobius minutus	-1.5 to 0.3
Laccophilus hyalinus	-2 to 0.6
Laccophilus minutus	-1.7 to 1
Lasiocephala basalis	-0.9 to -0.3
Lebertia inaequalis	-1.5 to -0.1
Lebertia insignis	-1.2 to 0.2
Lebertia pusilla	-1.2 to -0.9
Lebertia rivulorum	-0.9 to -0.3
Lebertia stigmatifera	-1.4 to -0.7
Lecane aculeata	-1.1 to 0.6
Lecane bulla	-1.1 to 0.6
Lecane closterocerca	-1.1 to 0.6
Lecane cornuta	-1.1 to 0.6
Lecane curvicornis	-1.1 to 0.6

Species	^{10}log TP
Lecane decipiens	-1.1 to 0.6
Lecane elsa	-1.1 to 0.6
Lecane flexilis	-1.1 to 0.6
Lecane furcata	-1.1 to 0.6
Lecane hamata	-1.1 to 0.6
Lecane hastata	-1.1 to 0.6
Lecane leontina	-1.1 to 0.6
Lecane ludwigii	-1.1 to 0.6
Lecane lunaris	-1.1 to 0.6
Lecane papuana	-1.1 to 0.6
Lecane proiecta	-0.4 to 0.6
Lecane quadridentata	-1.1 to 0.6
Lecane scutata	-1.1 to 0.6
Lecane signifera	-1.1 to 0.6
Lecane stenroosi	-1.1 to 0.6
Lecane tenuiseta	-1.1 to 0.6
Lepadella acuminata	-0.4 to 0.6
Lepadella latusimus	-1.1 to 0.6
Lepadella patella	-1.1 to 0.6
Lepadella quadricarinata	-1.1 to 0.6
Leptocerus tineiformis	-1.8 to -0.8
Leptophlebia vespertina	-0.4 to -0.2
Lestes sponsa	-1.5 to -0.7
Lestes viridis	-1.3 to 0.6
Libellula depressa	-1 to -0.5
Limnebius nitidus	-0.9 to -0.8
Limnebius truncatellus	-1.4 to -0.2
Limnephilus centralis	-1.2 to -1
Limnephilus decipiens	-1.3 to -0.3
Limnephilus extricatus	-1.3 to -0.5
Limnephilus lunatus	-1.7 to 0.6
Limnephilus rhombicus	-1.3 to -0.2
Limnesia connata	-0.4 to -0.2
Limnesia fulgida	-1.3 to -0.5
Limnesia koenikei	-1.5 to 0.2
Limnesia maculata	-2 to 0.3
Limnesia undulata	-1.5 to 0.3

Species	^{10}log TP	Species	^{10}log TP
Limnius volckmari	-1.4 to -0.8	*Microtendipes pedellus*	-1.4 to -0.4
Limnodrilus claparedeanus	-1.5 to -0.1	*Microtendipes rydalensis*	-1.7 to -1.6
Limnodrilus hoffmeisteri	-1.7 to 0.4	*Microvelia reticulata*	-2 to -0.2
Limnodrilus udekemianus	-1.5 to -0.1	*Mideopsis crassipes*	-1.3 to -0.3
Limnomysis benedeni	-1.8 to -0.6	*Mideopsis orbicularis*	-1.4 to -0.2
Limnoperla jaffueli	-2.2 to -0.9	*Molanna angustata*	-1.3 to 0.2
Lithoglyphus naticoides	-1 to -0.6	*Monommata longiseta*	-1.1 to 0.6
Lophocharis salpina	-1.1 to 0.6	*Monopelopia tenuicalcar*	-1.5 to -0.1
Luchoelmis cekalovici	-2.2 to -0.9	*Moorbdella fervida*	-0.8 to 0.7
Lumbriculus variegatus	-2 to 0.5	*Musculium lacustre*	-1.4 to 0.7
Lymnaea diaphana	-1.8 to -1.3	*Mystacides azureus*	-1.3 to -0.6
Lymnaea stagnalis	-1.5 to 0.6	*Mystacides longicornis*	-1.4 to 0.2
Lype phaeopa	-1.3 to 0	*Mystacides niger*	-1.3 to 0.2
Lype reducta	-1.4 to -0.3	*Mytilina bisulcata*	-1.1 to 0.6
Macronychus glabratus	-1 to -0.6	*Mytilina ventralis*	-1.1 to 0.6
Macropelopia adaucta	-2 to -0.7	*Nais barbata*	-0.3 to 0.2
Macropelopia nebulosa	-1.5 to -0.1	*Nais communis*	-1.8 to -0.6
Marstoniopsis scholtzi	-1.3 to -0.6	*Nais elinguis*	-1.7 to 0.6
Mastigoptila longicornuta	-2.2 to -0.9	*Nais pardalis*	-1.2 to -0.7
Meridialaris chiloeensis	-2 to -1.6	*Nais variabilis*	-1.8 to -0.8
Meridialaris laminata	-2 to -1.3	*Nanocladius bicolor*	-1.3 to -0.3
Mesovelia furcata	-1.3 to -0.6	*Nanocladius rectinervis*	-1.2 to -0.3
Metrichia neotropicalis	-2.2 to -0.9	*Nebrioporus depressus*	-1.7 to 0.6
Metriocnemus hirticollis	-0.7 to -0.5	*Nemoura avicularis*	-1.5 to -0.1
Microchironomus tener	-1.3 to -0.2	*Nemoura cambrica*	-1.3 to -1
Micronecta minutissima	-1 to -0.4	*Nemoura cinerea*	-1.7 to 0.5
Micronecta scholtzi	-1.3 to -0.2	*Nemurella pictetii*	-1.5 to -0.4
Micropsectra apposita	-1.3 to -0.2	*Neoatopsyche chilensis*	-2.2 to -1.4
Micropsectra atrofasciata	-2 to -0.3	*Neomysis integer*	-0.8 to -0.7
Micropsectra bidentata	-1.2 to -0.7	*Neoplanorbis carinatus*	-1.8 to 0.6
Micropsectra dives	-1.3 to -1.2	*Neopsilochorema tricarinatum*	-2.2 to -1.4
Micropsectra fusca	-1.7 to -0.5	*Nepa cinerea*	-1.5 to 0.7
Micropsectra notescens	-1.4 to -0.2	*Neumania deltoides*	-1 to -0.2
Micropsectra polita	-1.9 to -1.8	*Neumania imitata*	-1.3 to -0.2
Micropterna lateralis	-1.7 to -0.5	*Neumania limosa*	-2 to -0.2
Micropterna sequax	-1.7 to 0.1	*Neureclipsis bimaculata*	-1.3 to 0.3
Microtendipes chloris	-1.4 to 0.1	*Nigronia serricornis*	-1 to -0.6

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Species	^{10}log TP
Noterus clavicornis	-1.4 to 0.1
Noterus crassicornis	-1.4 to 0.3
Notholca acuminata	-0.4 to 0.6
Notidobia ciliaris	-1.2 to -0.3
Notonecta maculata	-1.5 to -0.3
Notonecta obliqua	-1.4 to -0.6
Notonecta viridis	-1.4 to -0.4
Notoperlopsis femina	-2.2 to -1.4
Nousia delicata	-2 to -1.5
Ochthebius bicolon	-1.4 to 0.3
Ochthebius minimus	-1.5 to -0.4
Odagmia ornata	-1.7 to 0.4
Odagmia spinosa	-1.3 to -0.1
Odontomesa fulva	-1.3 to 0.2
Oecetis furva	-1.3 to -0.5
Oecetis lacustris	-1.2 to 0.5
Oecetis ochracea	-1.3 to 0.3
Oligotricha striata	-1 to -0.7
Omphiscola glabra	-1.3 to 0.1
Ophidonais serpentina	-1.7 to 1.2
Optioservus fastiditus	-1.4 to -1.3
Optioservus ovalis	-1.2 to -1
Orconectes limosus	-1.3 to -0.1
Orectochilus villosus	-1.1 to -0.1
Orthocladius dentifer	-1.5 to -1.4
Oulimnius rivularis	-2 to -0.5
Oulimnius tuberculatus	-1.3 to -0.1
Oxyethira bidentata	-1.5 to -0.9
Pagastia orthogonia	-1.4 to -1.3
Parachironomus arcuatus	-1.3 to -0.3
Paracladius conversus	-1.7 to 0.2
Paracladopelma camptolabis	-1.5 to -0.9
Paracladopelma laminata	-1.3 to 0.1
Paracladopelma nigritula	-1.5 to 0.1
Paragnetina media	-1.3 to -1.2
Paralauterborniella nigrohalteralis	-1.3 to -0.7
Paraleptophlebia mollis	-1.6 to -1.5

Species	^{10}log TP
Paramerina cingulata	-1.5 to -0.7
Parametriocnemus lundbecki	-1.2 to -0.6
Parametriocnemus stylatus	-1.4 to -0.8
Parapoynx stratiotata	-1.1 to -0.2
Parasericostoma ovale	-2.2 to -0.9
Paratanytarsus austriacus	-0.8 to -0.5
Paratanytarsus confusus	-1.4 to -1.3
Paratanytarsus dissimilis	-1.3 to -0.1
Paratanytarsus grimmii	-1.3 to -0.6
Paratanytarsus lauterborni	-0.8 to -0.3
Paratanytarsus tenellulus	-1.2 to -0.5
Paratanytarsus tenuis	-1 to -0.3
Paratendipes albimanus	-1.3 to 0.1
Paratrichocladius rufiventris	-1.3 to 0
Pedicia rivosa	-1.5 to -0.5
Peltodytes caesus	-2 to 0.6
Penaphlebia chilensis	-2 to -1.5
Perla genualis	-2.2 to -1.4
Phaenopsectra dyari	-1.4 to -1.3
Phryganea bipunctata	-1.4 to -0.3
Physa acuta	-1.3 to 0.8
Physa fontinalis	-2 to 1
Physella acuta	-1.8 to -0.2
Piona alpicola	-1.3 to -0.4
Piona carnea	-0.8 to -0.5
Piona coccinea	-1.4 to 0.2
Piona conglobata	-1.3 to 0.2
Piona imminuta	-0.7 to -0.2
Piona neumani	-1.3 to -0.2
Piona rotundoides	-1.3 to -0.2
Piona stjoerdalensis	-0.8 to -0.7
Piona variabilis	-2 to -0.1
Pionacercus vatrax	-0.6 to -0.2
Pionopsis lutescens	-1.5 to 0.2
Piscicola geometra	-2 to 0.5
Pisidium amnicum	-1.3 to -0.1
Pisidium casertanum	-2 to -0.1

Species	^{10}log TP	Species	^{10}log TP
Pisidium henslowanum	-1.3 to 0.2	*Potamopyrgus antipodarum*	-1.8 to 0.1
Pisidium milium	-1.2 to -0.2	*Potamothrix hammoniensis*	-1.3 to -0.1
Pisidium moitessierianum	-1.3 to -0.1	*Potamothrix moldaviensis*	-1.4 to -0.1
Pisidium nitidum	-1.3 to -0.2	*Potthastia gaedii*	-1.2 to -1
Pisidium personatum	-1.4 to -0.7	*Potthastia longimana*	-1.4 to 0.5
Pisidium pulchellum	-1 to -0.2	*Proasellus coxalis*	-1.8 to 0.4
Pisidium subtruncatum	-1.3 to -0.1	*Proasellus meridianus*	-2 to 0.6
Pisidium supinum	-1.3 to -0.2	*Procladius choreus*	-1.5 to -0.6
Planaria torva	-1.8 to -1.2	*Procloeon bifidum*	-1 to -0.4
Planorbarius corneus	-2 to 0.6	*Prodiamesa olivacea*	-1.7 to 1.2
Planorbis planorbis	-2 to 0.6	*Progomphus obscurus*	-1 to -0.6
Platambus maculatus	-1.4 to -0.1	*Promoresia elegans*	-0.8 to -0.3
Plationus patulus	-1.1 to 0.6	*Prostoma graecense*	-1.6 to -1.5
Platycnemis pennipes	-1.3 to -0.1	*Psammoryctides barbatus*	-1.2 to 0.4
Platyias quadricornis	-1.1 to 0.6	*Psectrocladius obvius*	-1.2 to -0.7
Plectrocnemia conspersa	-1.7 to -0.3	*Psectrocladius platypus*	-1 to -0.7
Ploesoma truncatum	-1.1 to 0.6	*Psectrocladius psilopterus*	-2 to -0.7
Podura aquatica	-1.3 to -0.4	*Psectrotanypus varius*	-2 to 1.2
Polycelis felina	-1.5 to -0.5	*Psephenus herricki*	-1 to -0.8
Polycelis nigra	-1.3 to 0.3	*Pseudanodonta complanata*	-1.2 to -0.2
Polycelis tenuis	-1.7 to 0.5	*Psychomyia flavida*	-1.7 to -0.1
Polycentropus irroratus	-0.5 to -0.4	*Pteronarcella badia*	-1.7 to -0.1
Polypedilum aviceps	-1.7 to -1.6	*Pteronarcys californica*	-1.7 to -0.1
Polypedilum bicrenatum	-1.3 to -0.2	*Ptychoptera contaminata*	-1.3 to 0.4
Polypedilum convictum	-1.3 to -0.6	*Pyrrhosoma nymphula*	-2 to -0.5
Polypedilum flavum	-1.2 to -1	*Quistodrilus multisetosus*	-1.3 to -0.2
Polypedilum illinoense	-1 to -0.8	*Radix auricularia*	-1.3 to 0.2
Polypedilum laetum	-1.7 to -1	*Radix balthica*	-1 to -0.2
Polypedilum nubeculosum	-1.3 to -0.2	*Radix ovata*	-1.8 to 0.2
Polypedilum scalaenum	-1.7 to -0.1	*Radix peregra*	-2 to 0.8
Polypedilum sordens	-1.3 to -0.3	*Ranatra linearis*	-1.3 to -0.6
Polypedilum uncinatum	-1 to -0.5	*Rhantus exsoletus*	-2 to 0.6
Pompholyx sulcata	-1.1 to 0.6	*Rhantus suturalis*	-1.1 to 0.1
Porhydrus lineatus	-0.2 to 0.1	*Rheocricotopus chalybeatus*	-1.7 to -0.1
Potamoperla myrmidon	-2.2 to -0.9	*Rheocricotopus effusus*	-1.1 to -0.7
Potamophylax nigricornis	-1.7 to -0.7	*Rheocricotopus fuscipes*	-1.7 to 0
Potamophylax rotundipennis	-1.7 to -0.5	*Rheocricotopus robacki*	-1.5 to -1.4

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Species	^{10}log TP
Rheotanytarsus pellucidus	-1.6 to -1.5
Rheotanytarsus photophilus	-1.3 to -0.9
Rhithrogena hageni	-1.7 to -0.1
Rhyacodrilus coccineus	-1.7 to -0.4
Rhyacophila brunnea	-1.7 to -0.1
Rhyacophila fasciata	-0.9 to -0.7
Rhyacophila fuscula	-1.6 to -1.5
Rhyacophila vaccua	-1.7 to -0.1
Segmentina nitida	-1.3 to 0.6
Sericostoma personatum	-1.7 to -0.4
Serratella deficiens	-1.4 to -1.3
Serratella serrata	-1.7 to -1.6
Sialis fuliginosa	-1.5 to -0.7
Sialis lutaria	-2 to 0.6
Sigara distincta	-2 to 0.6
Sigara falleni	-2 to 0.8
Sigara fossarum	-2 to -0.7
Sigara hellensii	-0.5 to 0.1
Sigara lateralis	-1.3 to 0.3
Sigara limitata	-0.7 to 1
Sigara nigrolineata	-1.5 to 1.2
Sigara scotti	-2 to -0.7
Sigara semistriata	-2 to 1.2
Sigara striata	-2 to 1.2
Silo nigricornis	-1.7 to -0.3
Simulium argyreatum	-1.2 to -0.3
Simulium jenningsi	-1.3 to -1.2
Simulium morsitans	-1.2 to -0.8
Simulium tuberosum	-1.7 to -1.6
Simulium venustum	-1 to -0.6
Simulium vittatum	-1 to -0.8
Sinantherina spinosa	-1.1 to 0.6
Slavina appendiculata	-1.3 to -0.5
Smicridea annulicornis	-2.2 to -0.9
Smicridea dithyra	-1.5 to -0.9
Smicridea frequens	-2.2 to -1
Spercheus emarginatus	-1.3 to 0.5
Sperchon clupeifer	-1.3 to -0.4
Sperchon compactilis	-1.7 to -0.7
Sperchon glandulosus	-1.4 to -0.7
Sperchon setiger	-1.7 to -0.3
Sperchon squamosus	-1.7 to -0.9
Sphaerium corneum	-1.5 to 0.6
Sphaerium novaezelandiae	-1.3 to 0.1
Sphaerium solidum	-1.3 to -0.2
Spirosperma ferox	-1.2 to 0
Stagnicola palustris	-1.4 to 1.2
Stenelmis crenata	-1 to -0.8
Stenonema mediopunctatum	-1.5 to -1.4
Stenonema modestum	-1.6 to -0.6
Stenonema terminatum	-1.6 to -1.5
Stenonema vicarium	-1.3 to -1.2
Stethelmis kaszabi	-2.2 to -1.7
Stictochironomus maculipennis	-1.3 to -0.4
Stictotarsus duodecimpustulatus	-1.3 to 0.6
Stylaria lacustris	-2 to 0.6
Stylodrilus heringianus	-1.4 to 0.1
Sublettea coffmani	-1.6 to -1.5
Symposiocladius lignicola	-1.7 to -1.2
Synorthocladius semivirens	-1.3 to -1.2
Taeniopteryx metequi	-1 to -0.6
Tanypus kraatzi	-1.3 to 0.5
Tanypus punctipennis	-1.3 to -0.2
Tanytarsus ejuncidus	-1 to -0.9
Tanytarsus eminulus	-1.3 to -0.3
Tanytarsus glabrescens	-1.4 to -1.3
Tanytarsus guerlus	-1.4 to -1.3
Tanytarsus verralli	-1.5 to -1.3
Testudinella patina	-1.1 to 0.6
Theodoxus fluviatilis	-0.9 to -0.6
Theromyzon tessulatum	-2 to 0.5
Thienemanniella flaviforceps	-1.2 to -0.5
Tinodes assimilis	-1.4 to -0.9
Tinodes waeneri	-1.3 to -0.7

Species	^{10}log TP
Tiphys latipes	-1.2 to -0.7
Tiphys ornatus	-1.4 to 0.2
Tiphys scaurus	-0.7 to -0.3
Tipula abdominalis	-1 to -0.6
Tipula lateralis	-1.5 to 0.5
Tipula luna	-0.9 to -0.3
Tipula luteipennis	-0.8 to 0.1
Tipula maxima	-1.5 to -0.7
Tipula melanoceros	-1.3 to -0.5
Tipula pruinosa	-1 to 0.9
Triaenodes bicolor	-2 to -0.1
Tribelos jucundus	-1 to -0.6
Trichocerca bicristata	-1.1 to 0.6
Trichocerca gracilis	-1.1 to 0.6
Trichocerca pusilla	-0.4 to 0.6
Trichocerca rattus	-0.4 to 0.6
Trichocerca similis	-1.1 to 0.6
Trichocerca stylata	-1.1 to 0.6
Trichocerca tigris	-1.1 to 0.6
Trichocerca weberi	-1.1 to 0.6
Trichotria tetractis	-1.1 to 0.6
Tricorythodes minutus	-1.7 to 0.7
Trocheta bykowskii	-1.2 to 0.8
Trocheta pseudodina	-1.5 to -0.9
Tubifex tubifex	-1.7 to 0.4
Tvetenia bavarica	-1.2 to -1
Tvetenia calvescens	-1.3 to -0.8
Tvetenia discoloripes	-1.4 to -1.1
Unio crassus	-1.2 to -0.3
Unio pictorum	-1.3 to 0.2
Unio tumidus	-1.3 to -0.1
Unionicola aculeata	-1.2 to -0.2
Unionicola crassipes	-1.3 to -0.1
Unionicola minor	-1.3 to -0.2
Unionicola tricuspis	-1.3 to -0.6
Valvata cristata	-1.3 to 0.2
Valvata macrostoma	-1.4 to -0.4
Valvata piscinalis	-1.7 to 0.6
Viviparus contectus	-1.3 to 0.5
Viviparus viviparus	-1.5 to -0.3
Wettina podagrica	-1.4 to -0.7
Wilhelmia equina	-0.1 to 0
Wolga spinfera	-1.1 to 0.6
Xenochironomus xenolabis	-1.3 to -0.1
Zaitzevia parvula	-1.7 to -0.1
Zapada cinctipes	-1.7 to -0.1
Zavrelimyia barbatipes	-1 to -0.8
(Sub)tropical	
Boyeria vinosa	-0.4 to 0.1
Calopteryx maculata	-0.4 to 0.1
Derovatellus lentus	-0.4 to -0.1
Gynacantha nervosa	-0.4 to 0.1
Mesovelia mulsanti	-0.4 to 0.1
Rhagovelia choreutes	-0.4 to 0.1
Schizothrix calcicola	-1.3 to -1
Sialis fuliginosa	-1 to -0.2
Tropisternus lateralis nimbatus	-0.4 to -0.2
(j) Macrophytes in streams	
Temperate	
Agrostis stolonifera	-2.7 to -2.4
Amblystegium fluviatile	-1.9 to -0.5
Amblystegium riparium	-1.5 to -0.6
Apium repens	-2.7 to -2.4
Brachythecium rivulare	-1.6 to -0.3
Butomus umbellatus	-0.3 to -0.2
Callitriche hamulata	-1.6 to -0.5
Callitriche platycarpa	-1.6 to -0.3
Callitriche stagnalis	-1.6 to -0.5
Caltha palustris	-2.5 to -2.4
Ceratophyllum demersum	-0.9 to -0.3
Cratoneuron commutatum	-2.7 to -2.4
Fontinalis antipyretica	-2.7 to -0.1

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Species	^{10}log TP
Fontinalis squamosa	-1.6 to -0.3
Glyceria fluitans	-2.5 to -0.1
Heteranthera dubia	-1.6 to -1.3
Hygrohypnum ochraceum	-1.6 to -0.3
Juncus subnodulosus	-2.5 to -2.4
Lemna minor	-2.4 to -0.3
Mentha aquatica	-2.7 to -2.4
Myosotis scorpioides	-2.5 to -2.4
Myriophyllum spicatum	-1 to -0.2
Najas marina	-1 to -0.3
Nasturtium officinale	-2.7 to -2.4
Nuphar lutea	-0.9 to -0.3
Phragmites australis	-2.5 to -2.4
Potamogeton crispus	-1 to -0.3
Potamogeton nodosus	-1 to -0.3
Potamogeton perfoliatus	-0.9 to -0.4
Ranunculus aquatilis	-1.6 to -0.3
Ranunculus fluitans	-0.8 to -0.5
Ranunculus peltatus	-1.6 to -0.1
Ranunculus penicillatus	-1.5 to -0.3
Ranunculus trichophyllus	-2.5 to -2.4
Rhynchostegium riparioides	-2.7 to -0.1
Scapania undulata	-1.9 to -0.7
Sparganium emersum	-1 to -0.3
Stuckenia pectinata	-1 to -0.3
Vallisneria americana	-1.6 to -1.3
Vallisneria spiralis	-0.9 to -0.3
Veronica anagallis-aquatica	-2.5 to -2.4
Veronica beccabunga	-2.7 to -2.4
(k) Non-silicon-based algae	
Temperate	
Actinastrum hantzschii	-1.2 to -0.3
Chlamydomonas angulosa	-1.2 to -0.1
Chlamydomonas globosa	-1.2 to -0.4
Cladophora glomerata	-1 to 0
Cryptomonas erosa	-1.2 to 0.1
Eudorina elegans	-0.5 to -0.1
Hariotina reticulata	-1.2 to -0.4
Lemanea fluviatilis	-1.9 to -0.7
Monactinus simplex	-1.2 to -0.1
Pediastrum boryanum	-1.2 to -0.1
Scenedesmus ellipsoideus	-1.1 to -0.3
Scenedesmus quadricauda	-0.4 to -0.1
Scenedesmus tetracerum	-1.2 to -0.1
Ulva intestinalis	-0.9 to -0.3
(Sub)tropical	
Actinastrum gracillimum	-1.8 to -1.2
Acutodesmus acuminatus	-1.3 to -1
Ankistrodesmus falcatus	-1.2 to -0.7
Ankistrodesmus fusiformis	-1.8 to -1.2
Audouinella hermannii	-3 to -1
Botryococcus braunii	-3 to -1
Botryococcus protuberans	-1.8 to -1.2
Closteriopsis acicularis	-1.8 to -1.2
Coelastrum microporum	-1.2 to -0.8
Coenococcus planctonicus	-1.8 to -1.2
Coleochaete orbicularis	-1.3 to -0.7
Crucigenia quadrata	-1.8 to -0.8
Crucigenia tetrapedia	-1.8 to -1.2
Crucigeniella rectangularis	-1.8 to -1.2
Cryptomonas brasiliensis	-1.8 to -1.2
Cryptomonas nordstedtii	-1.8 to -1.2
Desmodesmus abundans	-1.3 to -1
Dictyosphaerium ehrenbergianum	-1.8 to -1.2
Elakatothrix gelifacta	-1.3 to -1
Eudorina elegans	-1.8 to -1.2
Gloeocystis banneergattensis	-3 to -1
Gonium pectorale	-1.2 to -0.8
Hariotina reticulata	-1.2 to -0.8
Hydrosera whampoensis	-3 to -1
Kirchneriella obesa	-1.8 to -1.2
Kirchneriella roselata	-1.8 to -1.2

Species	^{10}log TP
Klebsormidium subtilissimum	-1.3 to -1
Korshikoviella limnetica	-1.1 to -0.7
Monactinus simplex	-1.3 to -1
Monoraphidium arcuatum	-1.8 to -1.2
Monoraphidium contortum	-1.8 to -1.2
Monoraphidium convolutum	-1.8 to -1.2
Monoraphidium fontinale	-1.8 to -1.2
Monoraphidium irregulare	-1.8 to -0.8
Monoraphidium komarkovae	-1.8 to -1.2
Monoraphidium minutum	-1.8 to -1.2
Monoraphidium tortile	-1.8 to -1.2
Mucidosphaerium pulchellum	-1.8 to -1.2
Nephrocytium lunatum	-1.8 to -1.2
Pandorina morum	-1.3 to -1
Parapediastrum biradiatum	-1.3 to -1
Pediastrum duplex	-3 to -0.7
Pseudopediastrum boryanum	-1.3 to -0.7
Scenedesmus bijuga	-1.3 to -0.8
Scenedesmus obliquus	-1.2 to -0.8
Scenedesmus quadricauda	-3 to -0.7
Schizomeris leibleinii	-1.2 to -0.8
Sphaerocystis planctonica	-3 to -1
Sphaerocystis schroeteri	-3 to -1
Stauridium tetras	-1.3 to -1
Tetraedron minimum	-1.3 to -0.7
Tetraedron trigonum	-1.2 to -0.8
Ulothrix tenerrima	-1.2 to -0.8
(l) Silicon-based algae	
Temperate	
Achnanthes abundans	-1.7 to -1
Achnanthes cotteriensis	-1.7 to -1
Achnanthes exigua	-1.1 to 0.3
Achnanthes lapidosa	-1.7 to -1.4
Achnanthes subhudsonis	-1.3 to 0.2
Achnanthidium biasolettianum	-0.8 to -0.2
Achnanthidium minutissimum	-2.7 to 0

Species	^{10}log TP
Achnanthidium rivulare	-1.7 to 0
Amphora inariensis	-1.4 to 0.1
Amphora ovalis	-1.3 to -1
Amphora pediculus	-1.3 to 0.2
Amphora perpusilla	-1.3 to -0.7
Asterionella formosa	-1.2 to -0.4
Aulacoseira granulata	-1.2 to 0.4
Aulacoseira italica	-1.2 to -0.1
Aulacoseira varians	-1.2 to -0.1
Bacillaria paxillifera	-1.1 to 0.4
Caloneis bacillum	-1.3 to 0.2
Cocconeis pediculus	-1.4 to 0
Cocconeis placentula	-1.6 to 0.2
Cyclostephanos dubius	-1.2 to -0.1
Cyclotella atomus	-0.8 to 0.3
Cyclotella comta	-1.2 to -0.1
Cyclotella meneghiniana	-1.2 to 0.2
Cyclotella pseudostelligera	-1.1 to 0.3
Cymatopleura elliptica	-1.2 to -0.5
Cymatopleura solea	-1.2 to -0.1
Cymbella affinis	-1.3 to -0.9
Cymbella prostrata	-1.3 to -1.2
Cymbella tumida	-1.4 to -0.1
Diadesmis contenta	-1.7 to -1
Diatoma vulgaris	-1.4 to 0.1
Didymosphenia geminata	-3 to -0.2
Discostella stelligera	-1.2 to -0.4
Encyonema minutum	-1.5 to 0
Eolimna minima	-1.5 to 0.2
Eolimna ruttneri	-1.1 to 0.3
Epithemia adnata	-1.2 to -0.1
Eunotia intermedia	-1.7 to -1.4
Fallacia pygmaea	-0.3 to 0
Fragilaria capucina	-1.1 to 0.2
Fragilaria crotonensis	-1.2 to -0.1
Frustulia rhomboides	-1.7 to -1
Frustulia vulgaris	-1.2 to 0.2

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Species	^{10}log TP
Geissleria decussis	-1.4 to 0
Gomphonema angustatum	-1 to -0.5
Gomphonema clavatum	-1.5 to -1
Gomphonema kobayashiae	-1.1 to 0.3
Gomphonema minutum	-1.4 to 0.1
Gomphonema olivaceum	-0.7 to -0.2
Gomphonema parvulum	-1.7 to 0.1
Gomphonema parvulum f. saprophilum	-1.3 to -1
Gyrosigma acuminatum	-1.2 to 0.1
Hippodonta capitata	-1.1 to 0.2
Karayevia oblongella	-1.7 to -0.5
Luticola goeppertiana	-0.8 to 0.4
Mayamaea agrestis	-1.1 to 0.3
Mayamaea atomus	-1.5 to 0.2
Melosira varians	-1.3 to 0.2
Navicula antonii	-1.6 to 0
Navicula canalis	-1.2 to 0.3
Navicula capitatoradiata	-1.3 to 0.1
Navicula cincta	-0.8 to -0.7
Navicula cryptocephala	-1.5 to 0.1
Navicula cryptotenella	-1.7 to 0.1
Navicula erifuga	-1.2 to 0.2
Navicula germainii	-1.2 to 0.2
Navicula gregaria	-1.2 to 0.2
Navicula heimansioides	-1.7 to -1.4
Navicula ingenua	-1.1 to 0.2
Navicula menisculus	-0.3 to 0
Navicula perminuta	-1.3 to 0.2
Navicula radiosa	-0.9 to -0.6
Navicula recens	-1 to 0.2
Navicula rhynchocephala	-1.2 to -0.1
Navicula rostellata	-1.2 to 0.2
Navicula schroeteri	-1.7 to -0.5
Navicula subminuscula	-1.1 to 0.2
Navicula symmetrica	-1.2 to 0.2
Navicula texana	-0.6 to -0.1
Navicula tridentula	-1.7 to -0.5

Species	^{10}log TP
Navicula tripunctata	-1.4 to 0.1
Navicula trivialis	-1.1 to 0.3
Navicula veneta	-1.7 to -0.5
Nitzschia acicularis	-0.5 to -0.1
Nitzschia amphibia	-1.1 to 0.3
Nitzschia archibaldii	-1.4 to 0.1
Nitzschia capitellata	-1.1 to 0.3
Nitzschia confinis	-0.7 to -0.3
Nitzschia constricta	-1 to -0.3
Nitzschia dissipata	-1.2 to 0.2
Nitzschia fonticola	-1.6 to 0
Nitzschia frustulum	-1.7 to -0.1
Nitzschia inconspicua	-1.7 to 0.3
Nitzschia liebetruthii	-1.3 to 0.2
Nitzschia linearis	-1.4 to 0
Nitzschia palea	-1.7 to 0.2
Nitzschia paleacea	-0.3 to -0.1
Nitzschia recta	-1.3 to 0.3
Nitzschia supralitorea	-1.7 to -0.5
Planothidium conspicuum	-1.2 to 0.3
Planothidium frequentissimum	-1.7 to 0.2
Planothidium lanceolatum	-1.3 to 0.2
Reimeria sinuata	-1.4 to 0.1
Rhoicosphenia abbreviata	-1.7 to 0.2
Sellaphora pupula	-1.1 to 0.3
Sellaphora seminulum	-1.7 to 0.3
Staurastrum tetracerum	-1.2 to -0.4
Staurosira construens	-1.1 to 0.2
Staurosirella pinnata	-1.2 to 0.1
Stephanodiscus hantzschii	-1.2 to -0.1
Surirella brebissonii	-1.3 to -0.5
Surirella linearis	-1.1 to -0.1
Surirella minuta	-1.4 to -0.6
Surirella splendida	-1.2 to -0.4
Synedra ulna	-1.3 to 0.1
Tabularia fasciculata	-1.4 to -1
Ulnaria acus	-1.2 to -0.1

Species	^{10}log TP
(Sub)tropical	
Achnanthes exigua	-3 to -0.1
Achnanthes inflata	-1.9 to -1
Achnanthes rupestris	-1.8 to -0.7
Achnanthidium biasolettianum	-3 to -0.1
Achnanthidium minutissimum	-3 to -0.1
Achnanthidium subsalsum	-1.9 to -0.7
Amphipleura lindheimeri	-3 to -0.7
Amphora copulata	-3 to -0.1
Amphora ovalis	-1.1 to -0.7
Aulacoseira agassizii	-3 to -0.1
Aulacoseira alpigena	-3 to -0.1
Aulacoseira ambigua	-3 to -0.4
Aulacoseira distans	-3 to 0.7
Aulacoseira granulata	-3 to 0.5
Aulacoseira herzogii	-1.8 to -1.2
Caloneis hyalina	-2.2 to -1.5
Caloneis limosa	-1.3 to -1
Cocconeis placentula	-1.9 to -0.7
Conticribra weissflogii	-3 to -0.4
Craticula cuspidata	-3 to 0.7
Cyclotella meneghiniana	-3 to 0.7
Cyclotella pseudostelligera	-3 to 0.7
Cymatopleura solea	-1.3 to -1
Cymbella tumida	-1.8 to -0.7
Cymbopleura naviculiformis	-3 to -0.1
Diadesmis contenta	-3 to 0.7
Diadesmis dissimilis	-3 to -0.4
Diatoma anceps	-3 to -0.1
Diatoma vulgaris	-3 to -0.1
Discostella stelligera	-2.2 to -1.2
Encyonema neomesianum	-3 to -0.1
Encyonema silesiacum	-3 to 0.7
Encyonema ventricosum	-3 to -1
Eunotia bilunaris	-3 to 0.5
Eunotia camelus	-3 to -0.1
Eunotia intermedia	-3 to -0.1
Eunotia monodon	-3 to -0.4
Eunotia papilio	-2.2 to -0.4
Eunotia pectinalis	-3 to -0.1
Eunotia praerupta	-3 to -0.4
Eunotia sudetica	-3 to -0.1
Fallacia monoculata	-2 to 0.7
Fragilaria capucina	-3 to 0.5
Fragilaria crotonensis	-1.2 to -0.7
Fragilaria goulardii	-3 to -1
Frustulia rhomboides	-3 to -0.1
Frustulia saxonica	-3 to -0.1
Frustulia vulgaris	-3 to -0.1
Gomphonema acuminatum	-3 to 0.7
Gomphonema angustatum	-3 to 0.5
Gomphonema augur	-3 to -0.1
Gomphonema augur var. turris	-2.2 to -0.4
Gomphonema gracile	-3 to -0.1
Gomphonema intricatum	-1.8 to -1
Gomphonema minuta	-1.2 to -0.8
Gomphonema olivaceum	-3 to -0.1
Gomphonema parvulum	-3 to 0.7
Gyrosigma scalproides	-1.8 to -0.7
Hantzschia amphioxys	-3 to -0.1
Luticola goeppertiana	-3 to 0.7
Melosira lineata	-1.8 to -1
Melosira varians	-3 to -0.1
Navicula clementis	-3 to -0.1
Navicula cryptocephala	-3 to 0.1
Navicula cryptotenella	-3 to 0.7
Navicula oblonga	-3 to -0.1
Navicula radiosa	-3 to -0.1
Navicula rostellata	-3 to -0.1
Navicula schroeteri	-1.8 to -0.7
Navicula viridula	-1.8 to -0.7
Neidium affine	-3 to -0.1
Neidium ampliatum	-1.8 to -1.5

Appendix S5.2

Species	^{10}log TP
Nitzschia acicularis	-1.8 to -1.2
Nitzschia amphibia	-1.9 to -0.7
Nitzschia gracilis	-1.8 to -1.2
Nitzschia linearis	-3 to 0.2
Nitzschia obtusa	-1.8 to -0.7
Nitzschia palea	-3 to 0.7
Nitzschia recta	-3 to 0.7
Nitzschia scalaris	-3 to -0.1
Nupela praecipua	-3 to 0.7
Orthoseira dendroteres	-3 to -0.4
Pinnularia brauniana	-3 to 0.7
Pinnularia divergens	-3 to -0.1
Pinnularia gibba	-3 to 0.7
Pinnularia lata	-3 to -0.1
Pinnularia legumen	-3 to -0.1
Pinnularia mesolepta	-1.8 to -1.2
Pinnularia microstauron	-2.2 to 0.7
Pinnularia rupestris	-1.8 to -1.2
Pinnularia subcapitata	-2 to 0.7
Planothidium dubium	-3 to -0.1
Planothidium heteroideum	-3 to -0.1
Planothidium lanceolatum	-3 to 0.7
Psammothidium subatomoides	-3 to 0.2
Rhoicosigma compactum	-1.8 to -0.1
Rhoicosphenia abbreviata	-3 to 0.7
Rhopalodia gibba	-1.2 to -0.7
Sellaphora pupula	-3 to 0.7
Stauroneis phoenicenteron	-3 to -0.1
Staurosira construens	-1.9 to -0.9
Stephanodiscus hantzschii	-1.3 to -0.7
Surirella angusta	-3 to -0.1
Surirella biseriata	-1.8 to -0.7
Surirella linearis	-3 to -0.1
Surirella minuta	-3 to -0.4
Surirella robusta	-3 to -0.1
Surirella tenera	-3 to -0.7
Synedra ulna	-3 to 0.5
Thalassiosira proschkinae	-1.3 to -0.7
Ulnaria delicatissima	-1.3 to -0.7
Ulnaria ulna	-3 to 0.7
Urosolenia eriensis	-1.8 to -1.2
Urosolenia longiseta	-1.8 to -1.2

Table S5.2.3 *Overview of the relative number of secies which are also found exclusively at TP levels below the defined optimum TP level (C_{opt}), at both TP conditions below and above C_{opt}, and at conditions exclusively above C_{opt}.*

Region	**Freshwater type**	**Trophic group**	**Exclusively below C_{opt}**	**Below and above C_{opt}**	**Exclusively above C_{opt}**
(Sub)tropical	Lake	Autotroph	0.55	0.41	0.04
(Sub)tropical	Lake	Heterotroph	0.22	0.33	0.44
(Sub)tropical	River	Autotroph	0.01	0.91	0.08
(Sub)tropical	River	Heterotroph	0.11	0.11	0.78
Cold	Lake	Autotroph	0.22	0.72	0.06
Cold	Lake	Heterotroph	0.07	0.89	0.04
Cold	River	Heterotroph	0	0.5	0.5
Temperate	Lake	Autotroph	0.2	0.69	0.12
Temperate	Lake	Heterotroph	0.17	0.67	0.16
Temperate	River	Autotroph	0.15	0.79	0.07
Temperate	River	Heterotroph	0.09	0.78	0.13
Xeric	Lake	Autotroph	0	0.93	0.07
Xeric	Lake	Heterotroph	0	0.5	0.5

Appendix S5.2

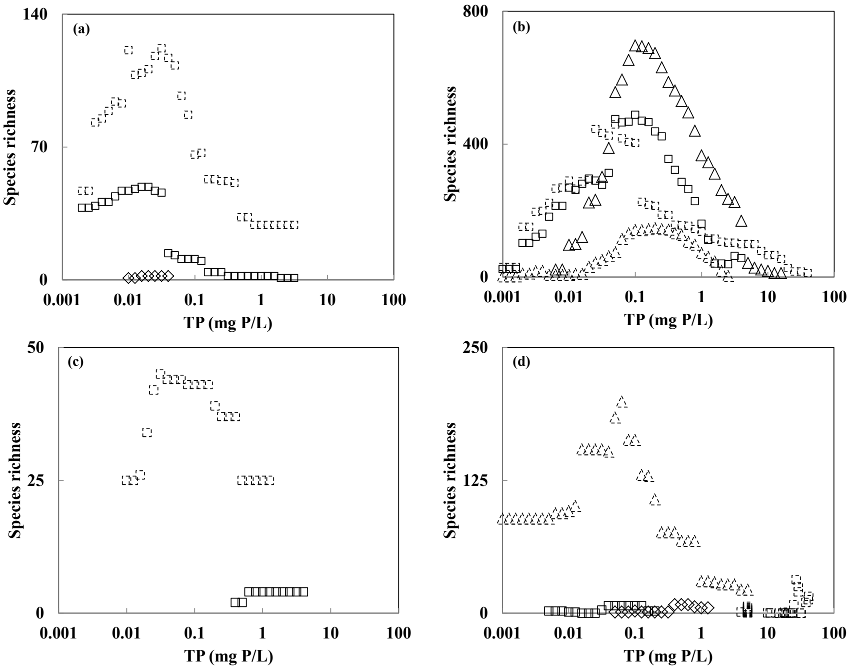

Figure S5.2.1 *Scatter plots of species richness – total phosphorus (TP) concentration across regions. Species richness – TP relationships used to identify* C_{opt} *(shown in Table 5.1 in the main text) and the empirical relative species richness (eRSR) used to derive the calculated relative species richness (cRSR) for* ***(a)*** *cold,* ***(b)*** *temperate,* ***(c)*** *xeric, and* ***(d)*** *(sub)tropical regions. Lakes and streams are shown in square and triangle symbols and autotrophs and heterotrophs are shown in dashed and continuous marker lines.*

Appendix S5.3 Internal validation and method testing at multiple spatial scales and different taxonomic groups

In a first step of the internal validation, we repeated the method we applied for the regions as described in the main text for more specific spatial scales. These are regions within realms, ecoregions within regions, and studies within regions. For example, the temperate region (Figure 2 of main text), is distributed among different world realms (Neotropic, Paleartic, etc). Here, evaluated how the log-logistic coefficients α and β differed across the different spatial units (Tables S5.3.1 – S5.3.4).

In a second step of the internal validation, we repeated the method for more specific taxonomic groups. We divided autotrophs into cyanobacteria, silicon-based algae, non-silicon-based algae, and macrophytes, and heterotrophs into fish and invertebrates. Again, we evaluated how the log-logistic coefficients α and β across the different taxonomic units (Tables S5.3.5 – S5.3.8).

Table S5.3.1 *Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), R^2 and p-value of the regressions at the* ***(a)*** *ecoregion level,* ***(b)*** *study, and* ***(c)*** *realm level of spatial aggregation for autotrophs in lakes.*

Aggregation level	**Studies**	**Species**	**SR_{max}**	**TP range**	**C_{opt}**	**α (95% CI)**	**β (95% CI)**	**$R^{2¶}$ / p-value**
(a) Ecoregion Cold								
Barents Sea Drainages[#]	1	7	7	0.004 to 0.079	0.01	1.59 (-3.26 to 6.44)	-1.63 (-4.21 to 0.94)	0.57 / <0.001
Canadian Arctic Archipelago	1	36	32	0.002 to 0.025	0.005	-1.94 (-2.02 to -1.85)	-0.10 (-0.17 to -0.02)	0.90 / <0.001
Iceland - Jan Mayen[#]	1	35	34	0.003 to 0.079	0.005	-0.96 (-1.05 to -0.87)	-0.32 (-0.39 to -0.25)	0.95 / <0.001
Northern Baltic Drainages	3	19	17	0.01 to 0.398	0.01	-1.22 (-3.45 to 1.00)	-0.01 (-0.81 to 0.79)	0.95 / <0.001
Temperate								

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
Alaska & Canada Pacific Coastal$^{\#}$	1	13	13	0.006 to 0.013	0.006	No successful fit with the log-logistic regression		
Biwa Ko$^{\#}$	1	23	23	0.006 to 0.01	0.006	No successful fit with the log-logistic regression		
Central & Western Europe	20	79	64	0.002 to 1.585	0.05	-0.52 (-0.57 to -0.48)	-0.28 (-0.33 to -0.24)	0.97 / <0.001
Dniester - Lower Danube$^{\#}$	1	6	6	0.025 to 0.2	0.05	-0.57 (-1.07 to -0.06)	-0.36 (-0.84 to 0.12)	0.68 / <0.001
Eastern Iberia	2	66	43	0.002 to 15.849	0.316	1.10 (1.02 to 1.18)	-0.36 (-0.44 to -0.28)	0.93 / <0.001
English - Winnipeg Lakes	3	36	34	0.006 to 0.398	0.013	-1.26 (-1.35 to -1.16)	-0.16 (-0.19 to -0.12)	0.99 / <0.001
Gulf of Venice Drainages	3	41	41	0.003 to 0.032	0.006	-1.59 (-1.83 to -1.36)	-0.27 (-0.54 to 0.00)	0.73 / <0.001
Italian Peninsula & Islands$^{\#}$	1	40	40	0.025 to 0.1	0.04	No successful fit with the log-logistic regression		
Laguna dos Patos$^{\#}$	1	1	10	0.02 to 0.158	0.02	No successful fit with the log-logistic regression		
Laurentian Great Lakes	4	52	52	0.002 to 0.025	0.016	-1.60 (-1.61 to -1.60)	-0.010 (-0.013 to 0.001)	1.00 / <0.001
Lower Parana	2	15	14	0.01 to 1.585	0.02	-0.98 (-1.00 to -0.95)	-0.05 (-0.07 to -0.03)	0.98 / <0.001
Lower Yangtze	5	50	47	0.013 to 0.631	0.05	-0.64 (-0.71 to -0.58)	-0.24 (-0.30 to -0.18)	0.95 / <0.001
New Zealand$^{\#}$	1	98	98	0.002 to 0.1	0.002	No successful fit with the log-logistic regression		
Northeast US & Southeast Canada Atlantic Drainages$^{\#}$	2	88	88	0.002 to 0.05	0.025	-1.05 (-1.91 to -0.19)	-0.14 (-0.54 to 0.26)	0.77 / 0.001
Northern British Isles	6	43	25	0.002 to 0.079	0.02	-1.38 (-1.44 to -1.32)	-0.13 (-0.19 to -0.08)	0.96 / <0.001
Oregon & Northern California Coastal$^{\#}$	1	27	27	0.025 to 0.032	0.025	No successful fit with the log-logistic regression		

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
Scotia - Fundy	1	54	33	0.003 to 6.31	0.003	0.60 (0.30 to 0.89)	-0.83 (-1.12 to -0.54)	0.77 / <0.001
Southern Baltic Lowlands#	2	117	117	0.02 to 0.2	0.025	No successful fit with the log-logistic regression		
St.Lawrence	3	36	36	0.001 to 0.032	0.005	-1.55 (-1.70 to -1.41)	-0.23 (-0.39 to -0.08)	0.83 / <0.001
Upper Danube	3	27	21	0.006 to 0.316	0.01	-0.90 (-0.16 to -0.63)	-0.71 (-1.10 to -0.32)	0.71 / <0.001
Upper Mackenzie#	3	25	16	0.005 to 39.811	0.013	2.29 (-1.86 to 6.44)	-5.69 (-14.86 to 3.48)	0.51 / <0.001
Upper Mississippi#	1	16	16	0.04 to 0.063	0.04	No successful fit with the log-logistic regression		
Volga – Ural#	3	3	3	0.05 to 0.126	0.063	-0.80 (-1.61 to 0.02)	-0.22 (-1.03 to 0.59)	0.67 / 0.018
Western Iberia	5	59	59	0.02 to 15.849	0.2	0.60 (0.45 to 0.75)	-0.48 (-0.65 to -0.31)	0.84 / <0.001
Western Transcaucasia#	1	27	27	0.05 to 0.2	0.05	-0.65 (-0.74 to -0.57)	-0.13 (-0.21 to -0.05)	0.92 / <0.001
Xeric								
Western Mongolia	2	45	45	0.01 to 1.259	0.032	0.03 (-0.07 to 0.14)	-0.39 (-0.50 to -0.28)	0.91 / <0.001
(Sub)tropical								
Florida Peninsula#	1	5	5	0.032 to 0.2	0.05	-0.67 (-0.70 to -0.64)	-0.08 (-0.11 to -0.05)	0.97 / <0.001
Iguassu#	1	15	15	0.003 to 0.013	0.003	No successful fit with the log-logistic regression		
Northeastern Caatinga & Coastal Drainages#	3	26	16	0.005 to 0.794	0.631	No successful fit with the log-logistic regression		
Papaloapan#	1	3	3	0.631 to 7.943	1.259	No successful fit with the log-logistic regression		
Southeastern Ghats#	1	46	42	7.943 to 31.623	15.849	1.58	-0.20	0.72 /

Aggregation level	**Studies**	**Species**	**SR_{max}**	**TP range**	**C_{opt}**	**α (95% CI)**	**β (95% CI)**	**$R^{2\P}$ / p-value**
						(0.98 to 2.18)	(-0.78 to 0.39)	0.013
Western Taiwan[#]	1	5	5	0.005 to 0.079	0.005	No successful fit with the log-logistic regression		
(b) Study								
Cold								
Devlin & Finkelstein (2011)[#]		36	32	0.002 to 0.013	0.005	-1.85 (-2.22 to -1.49)	-0.21 (-0.57 to 0.16)	0.72 / 0.002
Hessen & Leu (2006)[#]		7	7	0.004 to 0.079	0.01	1.59 (-3.26 to 6.44)	-1.63 (-4.21 to 0.94)	0.57 / <0.001
Izaguirre *et al.* (1993)[#]		13	12	0.025 to 0.398	0.2	-0.01 (-1.87 to 1.85)	-0.2 (-1.31 to 0.77)	0.66 / 0.003
Karst-Riddoch *et al.* (2009)[#]		35	34	0.003 to 0.079	0.005	-0.96 (-1.05 to -0.87)	-0.32 (-0.39 to -0.25)	0.95 / <0.001
Mäkelä *et al.* (2004)[#]		16	16	0.01 to 0.05	0.01	No successful fit with the log-logistic regression		
Olrik (1998)[#]		2	2	0.126 to 0.398	0.126	No successful fit with the log-logistic regression		
Suutari *et al.* (2009)[#]		1	1	0.025 to 0.251	0.025	No successful fit with the log-logistic regression		
Vinocur & Pizarro (2000)		71	65	0.002 to 3.162	0.032	-0.01 (-0.15 to 0.12)	-0.70 (-0.87 to -0.54)	0.88 / <0.001
Temperate								
Armstrong *et al.* (2003)[#]		4	4	0.013 to 0.063	0.013	-1.19 (-1.19 to -1.19)	-0.01 (-0.008 to -0.007)	1.00 / <0.001
Bagella *et al.* (2010)[#]		27	27	0.05 to 0.2	0.05	-0.65 (-0.74 to -0.57)	-0.13 (-0.21 to -0.05)	0.92 / <0.001
Bennion *et al.* (1995)[#]		10	10	0.01 to 0.032	0.02	-1.17 (-6.35 to 4.01)	-0.16 (-2.35 to 2.04)	0.71 / 0.032
Cabecinha et al. (2009a)		51	51	0.04 to 15.849	0.2	0.60 (0.41 to 0.79)	-0.53 (-0.75 to -0.31)	0.79 / <0.001
Cabecinha *et al.* (2009b)		22	22	0.02 to 7.943	0.158	0.61 (0.41 to 0.81)	-0.43 (-0.65 to -0.22)	0.78 / <0.001

Aggregation level	**Studies**	**Species**	**SR_{max}**	**TP range**	**C_{opt}**	**α (95% CI)**	**β (95% CI)**	**R^2[¶] / p-value**
Capers *et al.* (2009)[#]		77	77	0.025 to 0.05	0.025	No successful fit with the log-logistic regression		
Caputo *et al.* (2008)[#]		15	7	0.006 to 3.162	0.025	No successful fit with the log-logistic regression		
Casco *et al.* (2009)		14	14	0.01 to 0.126	0.02	-0.98 (-0.99 to -0.96)	-0.05 (-0.06 to -0.04)	0.99 / <0.001
Chen *et al.* (2008)[#]		11	5	0.005 to 0.079	0.025	-1.07 (-1.21 to -0.92)	-0.18 (-0.32 to -0.04)	0.88 / <0.001
Coops *et al.* (2008)		4	4	0.04 to 0.2	0.05	No successful fit with the log-logistic regression		
Dasí *et al.* (1998)[#]		41	37	0.025 to 15.849	0.398	1.21 (1.09 to 1.34)	-0.32 (-0.43 to -0.20)	0.87 / <0.001
De Backer *et al.* (2010)[#]		2	2	0.04 to 0.316	0.126	No successful fit with the log-logistic regression		
Del Pozo *et al.* (2010)[#]		1	1	0.05 to 6.31	0.05	No successful fit with the log-logistic regression		
DeNicola *et al.* (2004)		15	6	0.005 to 0.063	0.016	-1.51 (-1.56 to -1.45)	-0.09 (-0.14 to -0.04)	0.95 / <0.001
Edlund *et al.* (2009)[#]		16	16	0.04 to 0.063	0.04	No successful fit with the log-logistic regression		
Ekdahl *et al.* (2007)		20	20	0.002 to 0.025	0.008	-1.609 (-1.610 to -1.608)	-0.0065 (-0.007 to -0.006)	1.00 / <0.001
Free *et al.* (2009)[#]		4	4	0.002 to 0.063	0.003	-1.04 (-1.20 to -0.89)	-0.19 (-0.29 to -0.08)	0.83 / <0.001
Gacia *et al.* (1994)		13	13	0.002 to 0.316	0.006	-1.55 (-1.63 to -1.47)	-0.19 (-0.26 to -0.12)	0.92 / <0.001
Gregory-Eaves *et al.* (2003)[#]		13	13	0.006 to 0.013	0.006	No successful fit with the log-logistic regression		
Haberman *et al.* (2010)[#]		1	1	0.02 to 0.2	0.02	No successful fit with the log-logistic regression		
Hausmann & Pienitz (2007)[#]		20	20	0.001 to 0.01	0.001	No successful fit with the log-logistic regression		
Hazewinkel *et al.* (2008)[#]		11	11	5.012 to 39.811	19.953	-1.17 (-1.62 to -0.71)	-0.39 (-0.70 to -0.08)	0.76 / <0.001
Hilt *et al.* (2010)[#]		19	17	0.01 to 0.05	0.032	1.68 (1.21 to 2.15)	-0.18 (-0.62 to 0.26)	0.77 / 0.009
Holz *et al.* (1997)[#]		2	2	0.126 to 0.398	0.126	No successful fit with the log-logistic regression		
Hough & Thompson (1996)[#]		18	18	0.016 to 0.025	0.016	No successful fit with the log-logistic regression		
Hsieh *et al.* (2010)[#]		23	23	0.006 to 0.01	0.006	No successful fit with the log-logistic regression		

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
Joniak *et al.* (2007) #		3	3	0.016 to 0.251	0.079	No successful fit with the log-logistic regression		
Kirilova *et al.* (2008) #		11	11	0.02 to 0.126	0.063	No successful fit with the log-logistic regression		
Kirilova *et al.* (2010) #		11	9	0.032 to 0.316	0.063	No successful fit with the log-logistic regression		
Köster & Pienitz (2006) #		11	11	0.002 to 0.032	0.002	-0.73 (-0.93 to -0.53)	-0.16 (-0.36 to 0.04)	0.71 / 0.001
Kuczyńska-Kippen & Joniak (2010b) #		6	6	0.025 to 1.585	0.063	No successful fit with the log-logistic regression		
Leitão & Léglize (2000) #		13	13	0.04 to 0.2	0.04	0.74 (0.29 to 1.19)	-0.42 (-0.66 to -0.18)	0.78 / <0.001
Lewin & Smoliński (2006) #		18	18	0.01 to 1	0.079	No successful fit with the log-logistic regression		
Mäemets *et al.* (2010) #		116	116	0.025 to 0.1	0.025	0.13 (-0.11 to 0.36)	-0.46 (-0.67 to -0.25)	0.83 / <0.001
McIntire *et al.* (2007) #		27	27	0.025 to 0.032	0.025	No successful fit with the log-logistic regression		
Moser *et al.* (2000) #		12	12	0.005 to 0.032	0.005	No successful fit with the log-logistic regression		
Moss *et al.* (2005) #		7	7	0.04 to 0.398	0.1	No successful fit with the log-logistic regression		
Naselli-Flores & Barone (1998) #		40	40	0.025 to 0.1	0.04	-0.41 (-0.71 to -0.11)	-0.39 (-0.79 to 0.01)	0.73 / <0.001
Nedbalová *et al.* (2006) #		11	11	0.002 to 0.01	0.006	No successful fit with the log-logistic regression		
Nixdorf & Deneke (1997) #		3	3	0.05 to 0.126	0.063	-1.89 (-4.11 to 0.33)	-0.13 (-1.88 to 1.62)	0.72 / 0.097
Özkan *et al.* (2010) #		4	4	0.025 to 0.063	0.025	-0.80 (-1.61 to 0.02)	-0.22 (-1.03 to 0.59)	0.67 / 0.018
Pacheco *et al.* (2010) #		1	1	0.02 to 0.158	0.02	No successful fit with the log-logistic regression		
Peretyatko *et al.* (2009) #		6	6	0.05 to 0.631	0.126	No successful fit with the log-logistic regression		
Pla *et al.* (2005) #		31	31	0.006 to 0.025	0.006	-0.27 (-0.28 to -0.26)	-0.04 (-0.050 to -0.035)	1.00 / <0.001
Reid (2005) #		98	98	0.002 to 0.1	0.002	No successful fit with the log-logistic regression		
Romo *et al.* (2007) #		3	3	0.016 to 0.02	0.016	No successful fit with the log-logistic regression		
Sager & Lachavanne (2009) #		4	3	0.003 to 0.079	0.01	No successful fit with the log-logistic regression		
Sass *et al.* (2010)		10	10	0.001 to 0.1	0.001	-1.14	-0.22	0.74 /

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
						(-1.34 to -0.95)	(-0.41 to -0.02)	<0.001
Schagerl *et al.* (2010) #		10	10	0.006 to 0.316	0.016	No successful fit with the log-logistic regression		
Schlegel *et al.* (1998) #		1	1	0.063 to 0.251	0.063	No successful fit with the log-logistic regression		
Serieyssol *et al.* (2009) #		10	10	0.013 to 0.016	0.013	No successful fit with the log-logistic regression		
Song *et al.* (2010) #		4	4	0.079 to 0.398	0.079	No successful fit with the log-logistic regression		
Srivastava *et al.* (1995) #		54	33	0.003 to 6.31	0.003	No successful fit with the log-logistic regression		
St. Jacques *et al.* (2005) #		11	11	0.002 to 0.025	0.002	0.60 (0.30 to 0.89)	-0.83 (-1.12 to -0.54)	0.77 / <0.001
Tarkowska-Kukuryk (2011) #		10	10	0.05 to 0.398	0.2	No successful fit with the log-logistic regression		
Tolotti *et al.* (2006) #		22	22	0.003 to 0.01	0.005	-0.53 (-0.86 to -0.20)	-0.14 (-0.58 to 0.31)	0.70 / 0.080
Tracy *et al.* (2003) #		18	18	0.016 to 0.02	0.016	-1.11 (-4.96 to 2.75)	-0.31 (-1.52 to 0.90)	0.65 / <0.001
Trevisan *et al.* (2010) #		22	22	0.006 to 0.032	0.006	No successful fit with the log-logistic regression		
Trigal *et al.* (2009) #		4	4	0.063 to 1.995	0.063	No successful fit with the log-logistic regression		
Unrein *et al.* (2010) #		1	1	0.251 to 1.585	0.251	No successful fit with the log-logistic regression		
Wunsam & Schmidt (1995) #		11	11	0.002 to 0.251	0.004	No successful fit with the log-logistic regression		
Xu *et al.* (2005)		13	13	0.05 to 0.631	0.05	-0.88 (-0.94 to -0.82)	-0.16 (-0.22 to -0.11)	0.91 / <0.001
Yang *et al.* (2006) #		26	26	0.04 to 0.158	0.05	0.20 (-0.16 to 0.56)	-0.28 (-0.46 to -0.09)	0.80 / <0.001
Ye *et al.* (2007)		9	9	0.013 to 0.2	0.025	-0.82 (-1.12 to -0.52)	-0.24 (-0.58 to 0.11)	0.71 / 0.001
Xeric								
Shinneman *et al.* (2009a) #		8	8	0.01 to 0.158	0.01	-0.74 (-0.82 to -0.66)	-0.13 (-0.20 to -0.06)	0.89 / <0.001
Shinneman *et al.* (2009b) #		40	40	0.01 to 1.259	0.032	-0.78 (-0.92 to -0.63)	-0.22 (-0.36 to -0.09)	0.82 / <0.001

Aggregation level	**Studies**	**Species**	**SR_{max}**	**TP range**	**C_{opt}**	**α (95% CI)**	**β (95% CI)**	**$R^{2¶}$ / p-value**
(Sub)tropical								
Bouvy *et al.* (2003)		13	13	0.005 to 0.2	0.005	-0.95 (-0.99 to -0.90)	-0.13 (-0.17 to -0.08)	0.94 / <0.001
Caballero *et al.* (2006) #		3	3	0.631 to 7.943	1.259	No successful fit with the log-logistic regression		
Chellappa *et al.* (2008) #		16	16	0.631 to 0.794	0.631	No successful fit with the log-logistic regression		
da Silva et al. (2005) #		15	15	0.003 to 0.013	0.003	No successful fit with the log-logistic regression		
Havens *et al.* (1996) #		5	5	0.032 to 0.2	0.05	-0.67 (-0.70 to -0.64)	-0.08 (-0.11 to -0.05)	0.97 / <0.001
Rajagopal *et al.* (2010) #		46	42	7.943 to 31.623	15.849	1.58 (0.98 to 2.18)	-0.20 (-0.78 to 0.39)	0.72 / 0.013
Wu & Kow (2010) #		5	5	0.005 to 0.079	0.005	No successful fit with the log-logistic regression		
(c) Realm								
Cold								
Neartic	2	36	32	0.002 to 0.025	0.005	-1.94 (-2.02 to -1.85)	-0.10 (-0.17 to -0.02)	0.90 / <0.001
Paleartic	6	61	56	0.003 to 0.398	0.01	-1.16 (-1.19 to -1.13)	-0.09 (-0.12 to -0.07)	0.98 / <0.001
Temperate								
Australasia#	1	98	98	0.002 to 0.1	0.002	No successful fit with the log-logistic regression		
Neartic	21	241	191	0.001 to 39.811	0.025	-1.09 (-1.34 to -0.84)	-0.88 (-1.15 to -0.61)	0.77 / <0.001
Neotropic	3	16	15	0.01 to 1.585	0.02	-0.96 (-0.99 to -0.94)	-0.06 (-0.07 to -0.04)	0.99 / <0.001
Paleartic	56	410	294	0.002 to 15.849	0.05	-0.40 (-0.53 to -0.28)	-0.57 (-0.70 to -0.44)	0.89 / <0.001
Xeric								
Western Mongolia	2	45	45	0.01 to 1.259	0.032	0.03	-0.39	0.91 /

Aggregation level	**Studies**	**Species**	**SR$_{max}$**	**TP range**	**C$_{opt}$**	**α (95% CI)**	**β (95% CI)**	**R^{2¶} / p-value**
						(-0.07 to 0.14)	(-0.50 to -0.28)	<0.001
Realm								
Paleartic	1	5	5	0.01 to 1.259	0.032	0.03 (-0.07 to 0.14)	-0.39 (-0.50 to -0.28)	0.91 / <0.001
(Sub)tropical								
Indo-Malay[#]	2	50	42	0.005 to 31.623	15.849	1.57 (0.98 to 2.18)	-0.20 (-0.78 to 0.39)	0.72 / 0.013
Neartic[#]	1	5	5	0.032 to 0.2	0.05	-0.67 (-0.70 to -0.64)	-0.08 (-0.11 to -0.05)	0.97 / <0.001
Neotropic	5	42	27	0.003 to 7.943	0.005	-1.31 (-1.54 to -1.09)	-0.6 (-0.83 to -0.37)	0.77 / <0.001

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10^{α} coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

[¶] $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{Corrected\,Total}}$, as defined by Schabenberger & Pierce (2001)

Table S5.3.2 *Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), R^2 and p-value of the regressions at the* ***(a)*** *ecoregion level,* ***(b)*** *study, and* ***(c)*** *realm level of spatial aggregation for autotrophs in streams.*

Aggregation level	**Studies**	**Species**	**SR$_{max}$**	**TP range**	**C$_{opt}$**	**α (95% CI)**	**β (95% CI)**	**R^{2¶} / p-value**
(a) Ecoregion								

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	R^{2}[¶] / p-value
Temperate								
Bass Strait Drainages[#]	1	27	25	0.02 to 0.316	0.04	-0.44 (-0.68 to -0.19)	-0.33 (-0.55 to -0.10)	0.78 / <0.001
Central & Western Europe	8	31	30	0.013 to 0.794	0.158	-0.26 (-0.30 to -0.21)	-0.08 (-0.12 to -0.04)	0.95 / <0.001
Gulf of Venice Drainages[#]	3	1	11	0.002 to 0.02	0.002	No successful fit with the log-logistic regression		
Northeast US & Southeast Canada Atlantic Drainages[#]	1	67	67	0.02 to 2.512	0.158	No successful fit with the log-logistic regression		
Southeastern Korean Peninsula	2	36	36	0.063 to 0.794	0.079	-0.11 (-0.17 to -0.06)	-0.14 (-0.19 to -0.08)	0.93 / <0.001
St.Lawrence*	1	2	2	0.025 to 0.05	0.025	No successful fit with the log-logistic regression		
Upper Danube[#]	2	14	14	0.002 to 0.004	0.003	No successful fit with the log-logistic regression		
Upper Mississippi	1	44	26	0.04 to 1.585	0.501	-0.07 (-0.10 to -0.04)	-0.08 (-0.11 to -0.05)	0.98 / <0.001
Upper Saskatchewan[#]	1	1	29	0.001 to 0.631	0.001	No successful fit with the log-logistic regression		
(Sub)tropical								
Florida Peninsula	1	64	64	0.05 to 0.2	0.079	-0.75 (-0.84 to -0.67)	-0.10 (-0.19 to 0.00)	0.92 / 0.001
Iguassu[#]	1	23	23	0.001 to 0.1	0.001	No successful fit with the log-logistic regression		
Papaloapan[#]	1	31	31	0.013 to 0.2	0.016	-0.6 (-0.69 to -0.50)	-0.15 (-0.23 to -0.08)	0.9 / <0.001
Upper Parana	3	122	122	0.001 to 5.012	0.016	-0.29 (-0.41 to -0.18)	-0.54 (-0.66 to -0.42)	0.91 / <0.001

(b) Studies

Aggregation level Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
Temperate							
Cantonati & Spitale (2009)$^{\#}$	1	1	0.002 to 0.02	0.002	-0.34 (-0.45 to -0.22)	-0.15 (-0.27 to -0.03)	0.83 / <0.001
Fabris *et al.* (2009)$^{\#}$	14	14	0.002 to 0.004	0.003	No successful fit with the log-logistic regression		
Ha *et al.* (2002)$^{\#}$	27	27	0.063 to 0.794	0.079	No successful fit with the log-logistic regression		
Ha *et al.* (1998)$^{\#}$	22	22	0.063 to 0.398	0.063	0.00 (-0.02 to 0.03)	-0.12 (-0.14 to -0.11)	0.99 / <0.001
Kirkwood *et al.* (2007)$^{\#}$	1	1	0.001 to 0.631	0.001	No successful fit with the log-logistic regression		
Leland & Porter (2000)$^{\#}$	44	26	0.04 to 1.585	0.501	No successful fit with the log-logistic regression		
Lewin (2006)$^{\#}$	1	1	0.501 to 0.631	0.501	-0.07 (-0.10 to -0.04)	-0.08 (-0.11 to -0.05)	0.98 / <0.001
Newall & Walsh (2005)$^{\#}$	27	25	0.02 to 0.316	0.04	No successful fit with the log-logistic regression		
Ponader *et al.* (2007)	67	67	0.02 to 2.512	0.158	-0.44 (-0.68 to -0.19)	-0.33 (-0.55 to -0.10)	0.78 / <0.001
Thiébaut (2006)$^{\#}$	30	30	0.013 to 0.794	0.158	0.24 (0.23 to 0.24)	-0.06 (-0.07 to -0.06)	1.00 / <0.001
Vis *et al.* (2008)$^{\#}$	2	2	0.025 to 0.05	0.025	-0.27 (-0.31 to -0.22)	-0.08 (-0.12 to -0.04)	0.96 / <0.001
(Sub)tropical							
Bere & Tundisi (2011)$^{\#}$	78	78	0.001 to 5.012	0.016	0.11 (0.03 to 0.19)	-0.28 (-0.36 to -0.20)	0.91 / <0.001
Bere &Tundisi (2010)$^{\#}$	12	12	0.01 to 3.162	0.063	1.44 (0.85 to 2.03)	-0.45 (-0.67 to -0.22)	0.79 / <0.001
Dunn *et al.* (2008)$^{\#}$	64	64	0.05 to 0.2	0.079	-0.75 (-0.84 to -0.67)	-0.10 (-0.19 to 0.00)	0.92 / 0.001
Perbiche-Neves *et al.* (2011)$^{\#}$	23	23	0.001 to 0.1	0.001	No successful fit with the log-logistic regression		
Train & Rodrigues (1998)$^{\#}$	55	55	0.016 to 0.063	0.016	No successful fit with the log-logistic regression		

Aggregation level	**Studies**	**Species**	**SR_{max}**	**TP range**	**C_{opt}**	**α (95% CI)**	**β (95% CI)**	**R^{2}[¶] / p-value**
Vázquez *et al.* (2011) [#]		31	31	0.013 to 0.2	0.016	-0.6 (-0.69 to -0.50)	-0.15 (-0.23 to -0.08)	0.90 / <0.001
(c) Realm Temperate								
Australasia[#]	1	27	25	0.02 to 0.316	0.04	-0.44 (-0.68 to -0.19)	-0.33 (-0.55 to -0.10)	0.78 / <0.001
Neartic	6	97	84	0.001 to 2.512	0.501	0.19 (0.17 to 0.22)	-0.09 (-0.12 to -0.07)	0.99 / <0.001
Paleartic	19	80	66	0.002 to 0.794	0.158	-0.20 (-0.22 to -0.17)	-0.11 (-0.14 to -0.09)	0.98 / <0.001
(Sub)tropical								
Neartic[#]	1	64	64	0.05 to 0.2	0.079	-0.75 (-0.84 to -0.67)	-0.10 (-0.19 to 0.00)	0.92 / 0.001
Neotropic[#]	5	154	154	0.001 to 5.012	0.016	-0.45 (-0.55 to -0.36)	-0.47 (-0.56 to -0.38)	0.94 / <0.001

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10^{α} coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

[¶] $Pseudo-R^2 = 1 - \frac{SS_{residual}}{SS_{Corrected\,Total}}$, as defined by Schabenberger & Pierce (2001)

Table S5.3.3 *Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), R^2 and p-value of the regressions at the* ***(a)*** *ecoregion level,* ***(b)*** *study, and* ***(c)*** *realm level of spatial aggregation for heterotrophs in lakes.*

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
(a) Ecoregion Cold								
Barents Sea Drainages	1	2	2	0.002 to 0.063	0.003	-1.34 (-1.47 to -1.22)	-0.24 (-0.37 to -0.10)	0.82 / <0.001
Northern Baltic Drainages	10	51	44	0.002 to 1.585	0.013	-1.43 (-1.46 to -1.40)	-0.03 (-0.05 to 0.00)	0.94 / <0.001
Temperate								
Bonaerensean Drainages#	1	4	4	1 to 3.981	1.585	No successful fit with the log-logistic regression		
Central & Western Europe	29	383	335	0.001 to 3.162	0.1	-0.24 (-0.26 to -0.21)	-0.21 (-0.24 to -0.19)	0.99 / <0.001
Dniester - Lower Danube	1	29	27	0.01 to 1.259	0.1	-0.23 (-0.40 to -0.06)	-0.36 (-0.57 to -0.15)	0.79 / <0.001
Eastern Iberia	4	15	14	0.013 to 0.398	0.05	-0.87 (-0.99 to -0.75)	-0.24 (-0.36 to -0.11)	0.85 / <0.001
English - Winnipeg Lakes#	2	1	3	0.004 to 0.006	0.004	No successful fit with the log-logistic regression		
Gulf of Venice Drainages#	1	14	14	0.003 to 0.01	0.005	-1.28 (-4.46 to 1.90)	-0.30 (-1.47 to 0.87)	0.65 / 0.001
Laguna dos Patos#	1	14	13	0.025 to 0.398	0.032	-0.38 (-0.49 to -0.26)	-0.17 (-0.27 to -0.06)	0.82 / <0.001
Laurentian Great Lakes#	1	37	37	0.005 to 0.02	0.005	No successful fit with the log-logistic regression		
Lower Parana	5	11	6	0.013 to 3.162	0.2	0.34 (-0.89 to 1.58)	-1.20 (-3.92 to 1.52)	0.52 / <0.001
Lower Yangtze#	6	145	95	0.002 to 0.794	0.025	0.06 (-0.75 to 0.87)	-1.23 (-2.33 to -0.13)	0.59 / <0.001
Middle Missouri#	1	1	5	0.003 to 0.008	0.003	No successful fit with the log-logistic regression		
Northeast US &	1	6	6	0.008 to 0.05	0.008	No successful fit with the log-logistic regression		

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
Southeast								
Canada Atlantic Drainages#								
Northern Anatolia#	2	2	2	0.079 to 0.631	0.079	No successful fit with the log-logistic regression		
Northern British Isles	3	17	17	0.005 to 0.04	0.01	-1.62 (-1.74 to -1.51)	-0.12 (-0.24 to -0.01)	0.85 / <0.001
Southern Baltic Lowlands#	1	5	5	0.02 to 0.2	0.02	No successful fit with the log-logistic regression		
Southern Iberia#	1	1	7	0.01 to 0.04	0.01	No successful fit with the log-logistic regression		
St.Lawrence	4	18	18	0.002 to 0.032	0.008	-1.59 (-1.68 to -1.51)	-0.09 (-0.18 to -0.01)	0.87 / <0.001
Upper Danube#	3	84	54	0.006 to 3.981	3.162	No successful fit with the log-logistic regression		
Upper Mackenzie	3	14	13	0.006 to 0.251	0.01	-0.95 (-1.10 to -0.81)	-0.32 (-0.48 to -0.17)	0.82 / <0.001
Upper Saskatchewan#	1	1	2	0.126 to 0.158	0.126	No successful fit with the log-logistic regression		
Western Iberia	4	40	33	0.001 to 1.995	0.1	0.13 (0.09 to 0.18)	-0.03 (-0.06 to 0.00)	0.86 / <0.001
Western Transcaucasia	1	23	23	0.05 to 0.2	0.1	-0.79 (-1.11 to -0.47)	-0.15 (-0.60 to 0.30)	0.72 / 0.052
Xeric								
Vegas – Virgin#	1	5	5	0.398 to 3.981	0.631	No successful fit with the log-logistic regression		
(Sub)tropical								
Florida Peninsula	2	7	7	0.032 to 0.2	0.04	-0.82 (-0.86 to -0.78)	-0.03 (-0.07 to 0.01)	0.91 / <0.001
Parnaiba	1	2	2	0.005 to 0.013	0.005	-1.93 (-2.06 to -1.8)	-0.09 (-0.23 to 0.05)	0.83 / 0.002

(b) Studies

Aggregation level	**Studies**	**Species**	**SR$_{max}$**	**TP range**	**C$_{opt}$**	**α (95% CI)**	**β (95% CI)**	**R^{2¶} / p-value**
Cold								
Ask *et al.* (2009) #		1	1	0.006 to 0.025	0.006	No successful fit with the log-logistic regression		
Erős *et al.* (2009) #		1	1	0.01 to 0.063	0.01	No successful fit with the log-logistic regression		
Jansson *et al.* (2010) #		2	2	0.006 to 0.01	0.006	No successful fit with the log-logistic regression		
Jyväsjärvi *et al.* (2009) #		31	31	0.002 to 0.032	0.002	No successful fit with the log-logistic regression		
Nyström *et al.* (2006) #		8	8	0.006 to 0.05	0.016	-1.21 (-1.27 to -1.14)	-0.09 (-0.13 to -0.04)	0.96 / <0.001
Olin *et al.* (2002) #		7	7	0.013 to 0.126	0.013	-0.885 (-0.886 to -0.884)	-0.0085 (-0.009 to -0.008)	1.00 / <0.001
Olin *et al.* (2010) #		10	10	0.006 to 0.05	0.016	-1.29 (-1.5 to -1.08)	-0.20 (-0.42 to 0.01)	0.8 / <0.001
Persson *et al.* (2004) #		3	3	0.002 to 0.01	0.002	No successful fit with the log-logistic regression		
Rydin *et al.* (2008) #		6	6	0.002 to 0.006	0.004	No successful fit with the log-logistic regression		
Vakkilainen *et al.* (2004)		3	3	0.079 to 1.585	0.251	-0.41 (-0.82 to -0.01)	-0.49 (-1.18 to 0.19)	0.59 / 0.001
Van Geest *et al.* (2007)		2	2	0.002 to 0.063	0.003	-1.34 (-1.47 to -1.22)	-0.24 (-0.37 to -0.1)	0.82 / <0.001
Vinocur & Pizarro (2000) #		1	1	0.016 to 3.162	0.016	No successful fit with the log-logistic regression		
Temperate								
Bagella *et al.* (2010)#		23	23	0.05 to 0.2	0.1	-0.68 (-0.76 to -0.60)	-0.23 (-0.30 to -0.16)	0.94 / <0.001
Beklioglu & Tan (2008)		2	2	0.079 to 0.631	0.079	-0.79	-0.15	0.72 /

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
						(-1.11 to -0.47)	(-0.60 to 0.30)	0.052
Bertolo *et al.* (2005)$^{\#}$		1	1	0.004 to 0.016	0.004	No successful fit with the log-logistic regression		
Carol *et al.* (2006)$^{\#}$		15	14	0.013 to 0.398	0.05	No successful fit with the log-logistic regression		
Casas *et al.* (2011)$^{\#}$		1	1	0.01 to 0.04	0.01	-0.87 (-0.99 to -0.75)	-0.24 (-0.36 to -0.11)	0.85 / <0.001
Casco *et al.* (2009)$^{\#}$		2	2	0.013 to 0.126	0.013	No successful fit with the log-logistic regression		
Castro & Gonçalves (2007)$^{\#}$		13	13	0.079 to 0.316	0.079	No successful fit with the log-logistic regression		
Čerba *et al.* (2010)$^{\#}$		10	10	0.01 to 1.259	0.01	No successful fit with the log-logistic regression		
Cheng *et al.* (2010)$^{\#}$		36	36	0.005 to 0.251	0.063	-0.19 (-0.37 to -0.02)	-0.43 (-0.61 to -0.25)	0.80 / <0.001
Coops *et al.* (2008)$^{\#}$		8	8	0.04 to 0.2	0.05	-0.5 (-0.64 to -0.36)	-0.13 (-0.24 to -0.02)	0.87 / <0.001
Cottenie *et al.* (2001)$^{\#}$		6	6	0.2 to 0.501	0.251	No successful fit with the log-logistic regression		
Cronin *et al.* (2006)$^{\#}$		1	1	0.003 to 0.008	0.013	-0.25 (-0.35 to -0.15)	-0.08 (-0.17 to 0.01)	0.96 / 0.001
De Backer *et al.* (2010)$^{\#}$		14	13	0.04 to 0.631	0.251	No successful fit with the log-logistic regression		
Frost *et al.* (2003)$^{\#}$		2	2	0.004 to 0.158	0.01	-0.21 (-0.29 to -0.12)	-0.10 (-0.19 to -0.01)	0.92 / <0.001
Füreder *et al.* (2006)$^{\#}$		54	54	3.162 to 3.981	3.162	No successful fit with the log-logistic regression		
Gelinas & Pinel-Alloul (2008)$^{\#}$		6	6	0.004 to 0.025	0.008	No successful fit with the log-logistic regression		
Haberman *et al.* (2010)$^{\#}$		5	5	0.02 to 0.2	0.02	-1.78 (-1.90 to -1.67)	-0.13 (-0.25 to -0.01)	0.86 / 0.001
Iglesias *et al.* (2011)$^{\#}$		14	13	0.025 to 2.512	0.032	No successful fit with the log-logistic regression		
Jeppesen *et al.* (1998)$^{\#}$		6	6	0.398 to 1	0.501	-0.36 (-0.43 to -0.30)	-0.12 (-0.18 to -0.07)	0.94 / <0.001
Kirilova *et al.* (2010)$^{\#}$		14	13	0.032 to 0.316	0.032	0.19 (-0.51 to 0.90)	-0.13 (-0.51 to 0.25)	0.78 / 0.002
Korosi *et al.* (2008)$^{\#}$		37	37	0.005 to 0.02	0.005	-0.59 (-0.74 to -0.44)	-0.2 (-0.36 to -0.04)	0.78 / <0.001
Kuczyńska-Kippen & Joniak (2010a)		13	13	0.001 to 0.790	0.1	-0.60	-0.21	0.72 /

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
						(-0.84 to -0.36)	(-0.50 to 0.09)	0.002
Kuczyńska-Kippen & Joniak (2010) #		14	14	0.1 to 0.316	0.1	No successful fit with the log-logistic regression		
Liu & Wang (2007) #		18	18	0.158 to 0.316	0.251	-0.20 (-0.38 to -0.01)	-0.25 (-0.45 to -0.06)	0.78 / <0.001
Lund *et al.* (2010) #		11	11	0.04 to 0.251	0.04	No successful fit with the log-logistic regression		
May (1995) #		21	21	0.002 to 0.251	0.002	No successful fit with the log-logistic regression		
May & O'Hare (2005) #		10	10	0.005 to 0.016	0.005	No successful fit with the log-logistic regression		
McGarrigle & Champ (1999) #		7	7	0.008 to 0.04	0.01	No successful fit with the log-logistic regression		
Meerhoff *et al.* (2003) #		4	4	0.158 to 0.251	0.158	-1.32 (-1.47 to -1.17)	-0.12 (-0.23 to 0.00)	0.84 / <0.001
Mehner *et al.* (2005) #		9	9	0.013 to 0.251	0.013	No successful fit with the log-logistic regression		
Mehner *et al.* (2007) #		30	30	0.006 to 0.631	0.006	No successful fit with the log-logistic regression		
Mieczan (2010) #		1	1	0.025 to 0.398	0.025	No successful fit with the log-logistic regression		
Nedbalová *et al.* (2006) #		35	34	0.002 to 0.01	0.006	No successful fit with the log-logistic regression		
Özkan *et al.* (2010) #		3	3	0.025 to 0.063	0.025	-1.89 (-4.19 to 0.42)	-0.13 (-1.90 to 1.64)	0.72 / 0.093
Pereira *et al.* (2002) #		29	24	0.001 to 1.259	1	No successful fit with the log-logistic regression		
Post *et al.* (2008) #		6	6	0.008 to 0.05	0.008	No successful fit with the log-logistic regression		
Prchalová *et al.* (2008) #		16	16	0.02 to 0.032	0.02	No successful fit with the log-logistic regression		
Quinlan & Smol (2010) #		2	2	0.003 to 0.032	0.003	No successful fit with the log-logistic regression		
STOWA (2010) #		259	241	0.01 to 3.162	0.05	No successful fit with the log-logistic regression		
Rosso *et al.* (2010) #		5	5	0.794 to 1.259	0.794	-0.21 (-0.25 to -0.17)	-0.25 (-0.28 to -0.21)	0.99 / <0.001
Sayer *et al.* (2010) #		7	7	0.1 to 0.501	0.1	0.11 (0.10 to 0.12)	-0.008 (-0.015 to 0.000)	1.00 / <0.001
Schulz *et al.* (2006) #		1	1	0.063 to 1	0.063	No successful fit with the log-logistic regression		
Shao *et al.* (2001) #		48	48	0.2 to 0.794	0.398	No successful fit with the log-logistic regression		
Sosnovsky & Quirós (2009) #		5	5	1 to 3.981	1.585	1.07 (-3.89 to 6.02)	-0.31 (-1.56 to 0.93)	0.65 / <0.001
St. Jacques *et al.* (2005) #		9	9	0.002 to 0.025	0.002	No successful fit with the log-logistic regression		

Aggregation level	**Studies**	**Species**	**SR_{max}**	**TP range**	**C_{opt}**	**α (95% CI)**	**β (95% CI)**	**R^{2}[¶] / p-value**
Stephen *et al.* (2004) [#]		1	8	0.2 to 1	0.2	No successful fit with the log-logistic regression		
Tarkowska-Kukuryk, M (2011) [#]		10	10	0.05 to 0.398	0.05	No successful fit with the log-logistic regression		
Tátrai *et al.* (2008) [#]		11	11	0.032 to 0.063	0.032	-0.03 (-0.31 to 0.26)	-0.32 (-0.48 to -0.16)	0.86 / <0.001
Tolotti *et al.* (2006) [#]		14	14	0.003 to 0.01	0.005	No successful fit with the log-logistic regression		
Tonn *et al.* (2004)		12	11	0.01 to 0.251	0.01	-1.28 (-4.46 to 1.90)	-0.30 (-1.47 to 0.87)	0.65 / 0.0006
Trigal *et al.* (2009)		2	2	0.063 to 1.995	0.063	-0.84 (-1.03 to -0.65)	-0.38 (-0.59 to -0.17)	0.78 / <0.001
Vakkilainen *et al.* (2004) [#]		5	3	0.05 to 1	0.2	No successful fit with the log-logistic regression		
Vidaković & Bogut (2004) [#]		9	9	0.1 to 1	0.1	No successful fit with the log-logistic regression		
Wang *et al.* (2007) [#]		35	35	0.002 to 0.025	0.002	No successful fit with the log-logistic regression		
Wen *et al.* (2011) [#]		24	24	0.016 to 0.1	0.016	No successful fit with the log-logistic regression		
Zambrano *et al.* (2006) [#]		11	11	0.032 to 0.501	0.079	No successful fit with the log-logistic regression		
Xeric								
Jocqué *et al.* (2007) [#]		5	5	0.398 to 3.981	0.631	No successful fit with the log-logistic regression		
(Sub)tropical								
Catalano *et al.* (2010) [#]		4	4	0.04 to 0.126	0.04	No successful fit with the log-logistic regression		
Havens *et al.* (1996) [#]		3	3	0.032 to 0.2	0.032	-0.65 (-0.75 to -0.55)	-0.11 (-0.20 to -0.02)	0.85 / <0.001
Lucca *et al.* (2010)		2	2	0.005 to 0.013	0.005	-1.93 (-2.06 to -1.80)	-0.09 (-0.23 to 0.05)	0.83 / 0.002
(c) Realm								
Cold								
Paleartic	13	53	48	0.002 to 1.585	0.013	-1.39 (-1.45 to -1.34)	-0.10 (-0.14 to -0.05)	0.93 / <0.001

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
Temperate								
Neartic	11	68	65	0.002 to 0.251	0.01	-1.54 (-1.61 to -1.48)	-0.13 (-0.19 to -0.07)	0.93 / <0.001
Neotropic	5	22	19	0.013 to 3.981	0.158	-0.04 (-0.18 to 0.10)	-0.43 (-0.6 to -0.26)	0.84 / <0.001
Paleartic	56	615	464	0.001 to 3.981	0.1	-0.19 (-0.23 to -0.15)	-0.24 (-0.28 to -0.20)	0.98 / <0.001
Xeric Neartic[#]	1	5	5	0.398 to 3.981	0.501	No successful fit with the log-logistic regression		
(Sub)tropical								
Neartic	2	7	7	0.032 to 0.2	0.04	-0.82 (-0.86 to -0.78)	-0.03 (-0.07 to 0.01)	0.91 / <0.001
Neotropic	2	2	2	0.005 to 0.013	0.005	-1.93 (-2.06 to -1.80)	-0.09 (-0.23 to 0.05)	0.83 / 0.002

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10^{α} coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

[¶] $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{Corrected\ Total}}$, as defined by Schabenberger & Pierce (2001)

Table S5.3.4 *Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), R^2 and p-value of the regressions at the* ***(a)*** *ecoregion level,* ***(b)*** *study, and* ***(c)*** *realm level of spatial aggregation for heterotrophs in streams.*

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
(a) Ecoregion								
Cold								
Iceland - Jan Mayen[#]	1	33	33	0.01 to 0.04	0.016	No successful fit with the log-logistic regression		
Temperate								
Appalachian Piedmont[#]	1	30	30	0.1 to 0.251	0.1	No successful fit with the log-logistic regression		
Central & Western Europe	10	573	520	0.01 to 15.849	0.158	0.02 (-0.01 to 0.05)	-0.30 (-0.32 to -0.27)	0.99 / <0.001
Laurentian Great Lakes[#]	1	34	34	0.04 to 3.162	0.04	No successful fit with the log-logistic regression		
Lower Parana[#]	1	77	77	0.079 to 3.981	0.398	No successful fit with the log-logistic regression		
Middle Missouri	1	33	33	0.02 to 5.012	0.2	0.03 (-0.06 to 0.11)	-0.11 (-0.18 to -0.03)	0.87 / <0.001
New Zealand[#]	2	2	2	0.05 to 1.259	0.05	No successful fit with the log-logistic regression		
Northeast US & Southeast Canada Atlantic Drainages	1	70	20	0.013 to 0.501	0.1	-0.84 (-0.92 to -0.75)	-0.10 (-0.18 to -0.02)	0.87 / 0.001
Patagonia	5	35	33	0.006 to 0.126	0.02	-1.02 (-1.12 to -0.93)	-0.22 (-0.32 to -0.11)	0.90 / <0.001
Southern Iberia[#]	1	1	5	0.01 to 0.025	0.01	No successful fit with the log-logistic regression		
Tennessee[#]	1	7	7	0.02 to 0.398	0.063	No successful fit with the log-logistic regression		
(Sub)tropical								
Florida Peninsula[#]	2	8	7	0.05 to 1.259	0.398	0.21 (0.02 to 0.39)	-0.15 (-0.29 to -0.01)	0.87 / <0.001
Upper Parana[#]	1	1	9	0.1 to 0.631	0.1	No successful fit with the log-logistic regression		

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
				(b) Studies				
Cold								
Friberg *et al.* (2009)[#]		2	2	0.01 to 0.04	0.016	No successful fit with the log-logistic regression		
Temperate								
Casas *et al.* (2011)[#]		1	1	0.01 to 0.025	0.01	No successful fit with the log-logistic regression		
de Paggi & Devercelli (2011)[#]		77	77	0.079 to 3.981	0.398	No successful fit with the log-logistic regression		
Douda, K (2010)[#]		2	2	0.063 to 0.501	0.063	No successful fit with the log-logistic regression		
Gucker *et al.* (2011)[#]		10	10	0.1 to 0.631	0.1	No successful fit with the log-logistic regression		
Hill *et al.* (2010)[#]		7	7	0.02 to 0.398	0.063	No successful fit with the log-logistic regression		
Lenat & Crawford (1994)[#]		30	30	0.1 to 0.251	0.1	No successful fit with the log-logistic regression		
Magbanua *et al.* (2010)[#]		2	2	0.05 to 1.259	0.05	No successful fit with the log-logistic regression		
Miserendino (2006)[#]		8	8	0.006 to 0.126	0.006	No successful fit with the log-logistic regression		
Miserendino (2006)		5	5	0.006 to 0.126	0.032	-1.17 (-1.28 to -1.06)	-0.18 (-0.29 to -0.08)	0.84 / <0.001
Miserendino & Archangelsky (2006)		5	5	0.006 to 0.126	0.006	-1.18 (-1.27 to -1.10)	-0.20 (-0.3 to -0.11)	0.90 / <0.001
Miserendino & Brand (2007)[#]		11	11	0.006 to 0.126	0.032	-0.41 (-1.99 to 1.17)	-2.15 (-5.06 to 0.76)	0.55 / <0.001
STOWA (2010)		566	514	0.01 to 15.849	0.158	-0.75 (-1.13 to -0.37)	-0.32 (-0.65 to 0.01)	0.74 / <0.001
Smiley *et al.* (2009)		34	34	0.04 to 3.162	0.04	0.02 (0.00 to 0.05)	-0.3 (-0.32 to -0.27)	0.99 / <0.001
Smith *et al.* (2007)[#]		70	20	0.013 to 0.501	0.1	No successful fit with the log-logistic regression		
Tate & Heiny (1995)[#]		33	33	0.02 to 5.012	0.158	-0.84 (-0.92 to -0.75)	-0.10 (-0.18 to -0.02)	0.87 / 0.001
Vermonden *et al.* (2009)[#]		21	21	0.016 to 0.158	0.016	0.03 (-0.06 to 0.11)	-0.11 (-0.18 to -0.03)	0.88 / <0.001
(Sub)tropical								

Aggregation level	**Studies**	**Species**	**SR_{max}**	**TP range**	**C_{opt}**	**α (95% CI)**	**β (95% CI)**	**R^2[¶] / p-value**
Bere & Tundisi (2010)[#]		1	1	0.1 to 0.631	0.1	No successful fit with the log-logistic regression		
Cowell *et al.* (2004)[#]		7	7	0.398 to 1.259	0.398	0.21 (0.02 to 0.39)	-0.15 (-0.29 to -0.01)	0.87 / <0.001
Dunn *et al.* (2008)[#]		1	1	0.05 to 0.1	0.05	No successful fit with the log-logistic regression		
				(c) Realm				
Cold								
Paleartic[#]	1	2	2	0.01 to 0.04	0.016	No successful fit with the log-logistic regression		
Temperate								
Australasia[#]	2	2	2	0.05 to 1.259	0.05	No successful fit with the log-logistic regression		
Neartic	5	156	107	0.013 to 5.012	0.1	0.02 (-0.07 to 0.11)	-0.39 (-0.48 to -0.30)	0.93 / <0.001
Neotropic[#]	6	112	86	0.006 to 3.981	0.079	No successful fit with the log-logistic regression		
Paleartic	17	574	520	0.01 to 15.849	0.158	0.02 (-0.01 to 0.05)	-0.30 (-0.32 to -0.27)	0.99 / <0.001
(Sub)tropical								
Neartic[#]	2	8	7	0.05 to 1.259	0.398	0.21 (0.02 to 0.39)	-0.15 (-0.29 to -0.01)	0.87 / <0.001
Neotropic[#]	3	1	9	0.1 to 0.631	0.1	No successful fit with the log-logistic regression		

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10^{α} coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

[¶] $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{Corrected\ Total}}$, as defined by Schabenberger & Pierce (2001)

Table S5.3.5 *Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), $R^{2¶}$ and p value of the regressions at different levels of spatial aggregation for different taxonomic groups of autotrophs in lakes.*

Aggregation level	**Studies**	**Species**	**SR_{max}**	**TP range**	**C_{opt}**	**α (95% CI)**	**β (95% CI)**	**$R^{2¶}$ / p-value**
(a) Cyanobacteria								
Cold	3	28	25	0.002 to 3.162	0.03	-0.28 (-0.39 to -0.17)	-0.5 (-0.61 to -0.39)	0.89 / <0.001
Temperate	20	28	20	0.006 to 12.589	0.06	-0.33 (-0.5 to -0.16)	-0.75 (-0.96 to -0.54)	0.80 / <0.001
(Sub)tropical	6	36	17	0.003 to 31.623	0.05	-0.71 (-1.63 to 0.22)	-1.72 (-3.29 to -0.16)	0.16 / <0.001
(b) Macrophyte								
$Cold^{\#}$	3	17	17	0.01 to 0.251	0.03	-1.22 (-2.28 to -0.17)	-0.01 (-0.39 to -0.37)	0.99 / <0.001
Temperate	27	253	233	0.001 to 6.31	0.05	-0.81 (-0.89 to -0.73)	-0.29 (-0.37 to -0.21)	0.90 / <0.001
(c) Non-silicon-based algae								
Cold	4	17	15	0.002 to 3.162	0.03	-0.17 (-0.27 to -0.06)	-0.54 (-0.66 to -0.42)	0.90 / <0.001
Temperate	31	115	62	0.002 to 15.849	0.1	0.65 (0.53 to 0.77)	-0.71 (-0.84 to -0.57)	0.90 / <0.001
(Sub)tropical	4	34	19	0.003 to 31.623	12.59	1.47 (1.27 to 1.67)	-0.16 (-0.39 to 0.07)	0.75 / 0.025
(d) Silicon-based algae								
Cold	4	101	79	0.002 to 3.162	0.01	-0.89	-0.56	0.93 /

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
						(-0.99 to -0.8)	(-0.65 to -0.47)	<0.001
Temperate	40	218	181	0.001 to 39.811	0.01	-0.59 (-0.74 to -0.44)	-0.73 (-0.89 to -0.58)	0.86 / <0.001
Xeric	2	45	45	0.01 to 1.259	0.03	0.03 (-0.07 to 0.14)	-0.39 (-0.50 to -0.28)	0.90 / <0.0001
(Sub)tropical[#]	5	25	13	0.003 to 31.623	15.85	No successful fit with the log-logistic regression		

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10^{α} coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

[¶] $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{Corrected\ Total}}$, as defined by Schabenberger & Pierce (2001)

Table S5.3.6 *Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), $R^{2¶}$ and p value of the regressions at different levels of spatial aggregation for different taxonomic groups of autotrophs in streams.*

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
(a) Cyanobacteria								
Temperate	4	9	7	0.063 to 1.585	0.08	-0.19 (-0.23 to -0.16)	-0.09 (-0.12 to -0.05)	0.96 / <0.001
(Sub)tropical	3	37	37	0.001 to 0.2	0.06	-0.87 (-0.95 to -0.8)	-0.13 (-0.20 to -0.05)	0.93 / < 0.001
(b) Macrophyte								
Temperate[#]	4	42	27	0.002 to 0.794	0.16	0.26 (-0.3 to -0.21)	-0.07 (-0.11 to -0.04)	0.95 / <0.001
(c) Non-silicon-based algae								
Temperate	5	14	13	0.013 to 1.259	0.4	-0.11 (-0.18 to -0.04)	-0.10 (-0.16 to -0.03)	0.94 / 0.003

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
(Sub)tropical	3	53	52	0.001 to 0.2	0.06	-0.96 (-1.06 to -0.86)	-0.14 (-0.24 to -0.04)	0.88 / < 0.001
(d) Silicon-based algae								
Temperate	7	117	101	0.001 to 2.512	0.1	0.12 (0.08 to 0.15)	-0.15 (-0.18 to -0.12)	0.97 / <0.001
(Sub)tropical	6	113	110	0.001 to 5.012	0.06	-0.11 (-0.19 to -0.04)	-0.4 (-0.48 to -0.33)	0.95 / < 0.001

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10^{α} coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

[¶] $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{Corrected\,Total}}$, as defined by Schabenberger & Pierce (2001)

Table S5.3.7 *Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), $R^{2¶}$ and p value of the regressions at different levels of spatial aggregation for different taxonomic groups of heterotrophs in lakes.*

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
(a) Fish								
Cold	9	14	13	0.002 to 0.126	0.01	-1.02 (-1.11 to -0.93)	-0.28 (-0.38 to -0.19)	0.92 / <0.001
Temperate	27	109	93	0.002 to 3.981	0.04	-0.35 (-0.39 to -0.32)	-0.23 (-0.26 to -0.19)	0.98 / <0.001
(Sub)tropical[#]	2	4	4	0.04 to 0.126	0.04	No successful fit with the log-logistic regression		
(b) Invertebrate								
Cold	8	40	37	0.002 to 3.162	0.01	-1.44 (-1.47 to -1.41)	-0.02 (-0.03 to -0.01)	0.97 / <0.001
Temperate	38	573	399	0.001 to 3.981	0.1	-0.16 (-0.21 to -0.11)	-0.25 (-0.29 to -0.20)	0.98 / <0.001
Xeric[#]	1	5	5	0.398 to 3.981	0.63	No successful fit with the log-logistic regression		
(Sub)tropical[#]	3	5	3	0.005 to 0.2	0.03	-0.65 (-0.75 to -0.55)	-0.11 (-0.20 to -0.02)	0.82 / <0.001

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10^{α} coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

[¶] $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{Corrected\ Total}}$, as defined by Schabenberger & Pierce (2001)

Table S5.3.8 *Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), $R^{2¶}$ and p value of the regressions at different levels of spatial aggregation for different taxonomic groups of heterotrophs in streams.*

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	$R^{2¶}$ / p-value
(a) Fish								
Cold[#]	6	1	7	0.01 to 0.04	0.01	No successful fit with the log-logistic regression		
Temperate[#]	4	47	46	0.01 to 3.162	0.1	1.00 (0.46 to 1.54)	-0.74 (-1.14 to -0.34)	0.65 / <0.001
(b) Invertebrate								
Cold[#]	1	1	5	0.016 to 0.04	0.02	No successful fit with the log-logistic regression		
Temperate	13	788	651	0.006 to 15.849	0.1	0.09 (0.05 to 0.13)	-0.32 (-0.36 to -0.29)	0.99 / <0.001
(Sub)tropical[#]	3	9	8	0.05 to 1.259	0.4	0.13 (-0.02 to 0.29)	-0.15 (-0.29 to -0.29)	0.83 / <0.001

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10^{α} coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

[¶] $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{Corrected\ Total}}$, as defined by Schabenberger & Pierce (2001)

Appendix S6.1 Stressor – response relationships

We employed the observational field data on TP concentration ranges where temperate heterotrophic species were observed in lakes and streams reported by Azevedo *et al.* (2013a) (species-specific TP threshold levels are shown in Table S5.2.2, chapter 5 of this thesis). We considered the maximum TP level of each species as the highest concentration at which the species was observed in the environment. Second, we constructed log-logistic regressions of with the maximum P levels for lake species (683 in total) and stream species (852 in total). The regressions were defined as

$$PNOF_w = \frac{1}{1+e^{-\left(\frac{\log_{10} C_w - \alpha_w}{\beta_w}\right)}} \qquad \text{(S6.1.1)}$$

where $PNOF_w$ is the potentially not occurring fraction (PNOF) of species in freshwater type w (i.e. lake or stream) at concentration C_w of TP. The regression coefficients α_w and β_w represent, respectively, the $\log_{10}$ TP concentration at which PNOF is 0.5 and the slope of the log-logistic function (Figure 6.1, main text).

Appendix S6.2

Appendix S6.2 Selection of grids and of concentration monitoring data

We selected European grids (resolution: 0.5° x 0.5°) that were located within one of the three European temperate zones (i.e. temperate coastal rivers, temperate flooplain rivers and wetlands, or temperate upland rivers), defined by Abell *et al.* (2008), Figure S6.2.1. These temperate regions comprise a large number of water bodies which are monitored for TP levels by the European Environment Agency, EEA (2013b). On average, there was one lake and stream monitoring station per 25 and 5.9km^2 of land area, respectively.

For each selected grid, we included the latest mean annual TP record (up to 2011) at each monitored station reported by the EEA (2013b). The locations of the monitoring stations reporting mean annual TP data are shown in Figure S6.2.2. We determined the concentration of P in each grid as the average of the TP concentrations of the monitoring stations for lakes and streams separately. For grids where no monitoring station was present, we used the mean average of the TP concentrations in the monitoring stations within a 0.5° distance from the grid. For grids where no monitoring station was present within a 0.5° distance, we used the monitoring stations within a 1.0° distance, and so on, until all continental European grids were assigned a TP concentration estimate. Finally, we determined the concentration of TP in freshwater *w* in grid *j* ($C_{w,j}$) as the mean of the individual annual mean TP concentrations in monitored lake or stream stations within *j*. Grid-specific $C_{w,j}$ concentrations are shown in Figure S6.2.3.

Figure S6.2.1 *Temperate European zone (dark grey).*

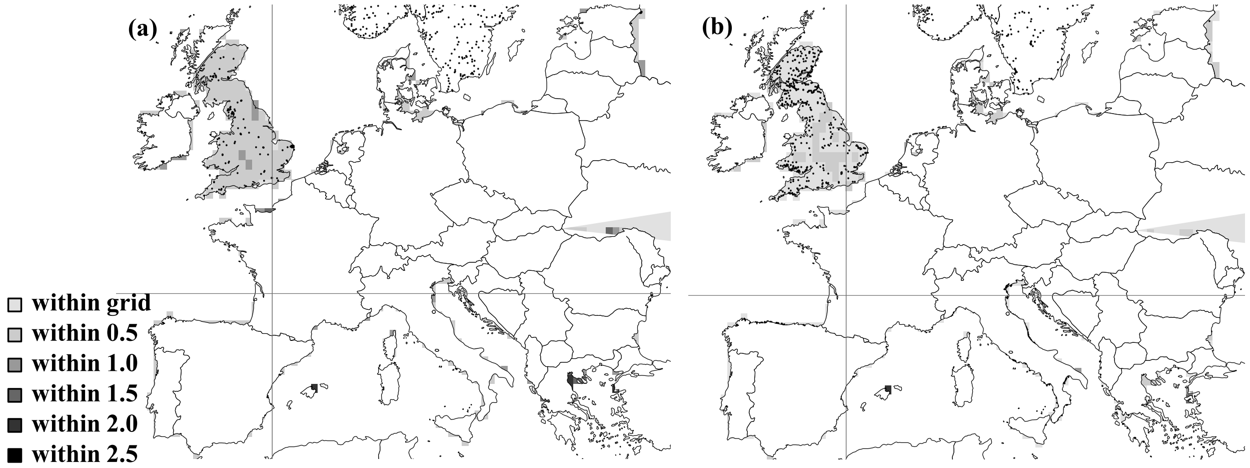

Figure S6.2.2 *Distance from grids to their nearest* ***(a)*** *lake (n = 2451) and* ***(b)*** *stream (n = 9525) monitoring station (dots) in Europe. The percentage of grids with a lake monitoring station within the grid and within a distance of 0.5°, 1.0°, 1.5°, 2.0°, and 2.5°, respectively, is 34%, 46%, 13%, 4%, 2%, and 1%. The percentage of grids with a stream monitoring station within the grid and within a distance of 0.5°, 1.0°, 1.5°, 2.0°, and 2.5°, respectively are 83%, 16%, <1%, <1%, <1%, and < 1%.*

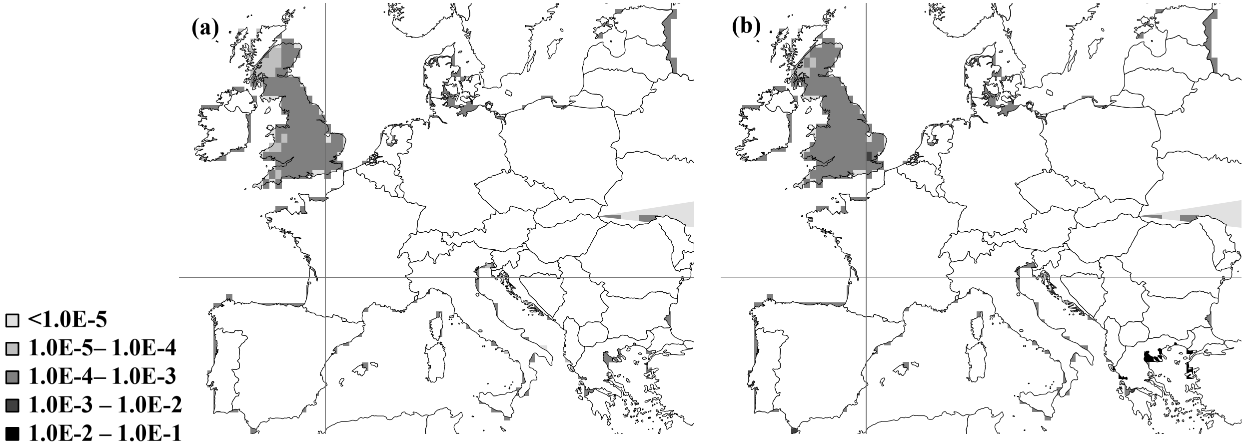

Figure S6.2.3 *Concentrations of mean annual TP ($C_{w,j}$, unit: kg P·m^{-3}), for* ***(a)*** *lakes and* ***(b)*** *streams in Europe.*

Appendix S6.3 Statistical analysis results

Grid-specific CFs based on the three effect models are shown in Figure S6.3.1 (for lakes) and Figure S6.3.2 (for streams). River-basin specific CFs based on the three effect models are shown in Table S6.3.1 for lakes and in Table S6.3.2 for streams. The results of the assumption tests of normality of residuals and of homogeneity of variances of the analysis of variance (ANOVA) are shown in Figure S6.3.3 and S6.3.4, respectively. The results of the ANOVA are shown in Table S6.3.3.

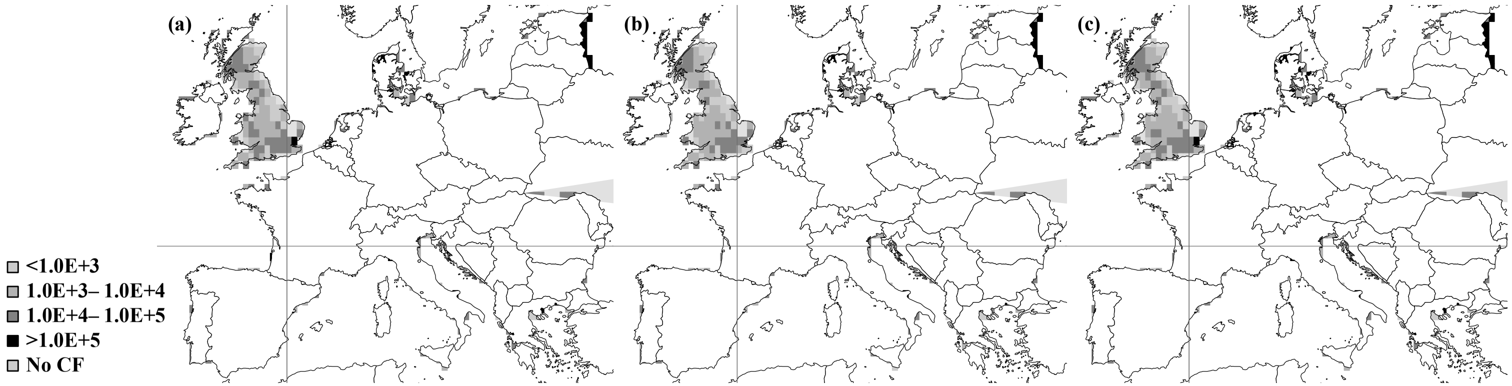

Figure S6.3.1 *Grid CFs (unit: day·kg $P^{-1}\cdot m^3$) for lakes determined with* ***(a)*** *marginal effect factors,* ***(b)*** *linear effect factors, and* ***(c)*** *average effect factors.*

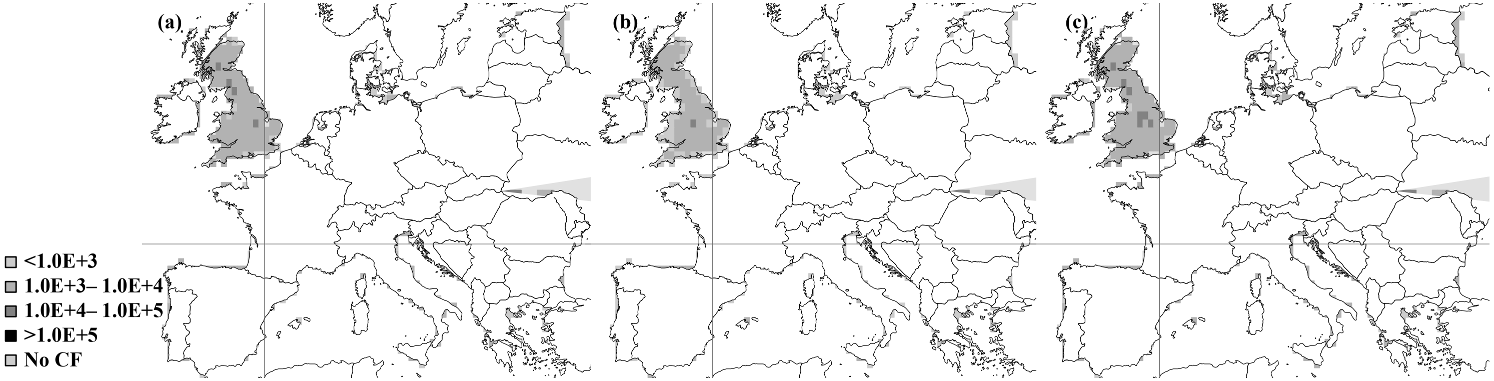

Figure S6.3.2 *Grid CFs (unit: day·kg* $P^{-1}\cdot m^{3}$*) for streams determined with* ***(a)*** *marginal effect factors,* ***(b)*** *linear effect factors, and* ***(c)*** *average effect factors.*

Table S6.3.1 *River-basin specific CF based on the three effect models (marginal – MEF, linear – LEF, and average – AEF) for* ***(a)*** *lakes and* ***(b)*** *streams. All units are reported as* $day \cdot kg\ P^{-1} \cdot m^3$.

River Basin	**CF$_{MEF}$**	**CF$_{LEF}$**	**CF$_{AEF}$**
(a) Lakes			
Adour	12084.37	8818.56	10910.6
Algarve	29926.6	21415.93	27142.06
Andalusia	34230.14	26948.19	30123.35
Anglian	23724.54	17571.44	23032.07
Black Sea	46081.95	55696.21	63273.45
Cantabrian	6181.93	4861.13	5977.29
Catalan	35923.2	27135.41	34501.39
Cavado	2565.54	1950.44	2278.46
Central Macedonia	2921.9	2166.69	2927.66
Corsica	14364.4	10387.74	14038.38
Cyprus	72105.15	52727.79	64602.98
Danube	26293.48	21445.01	26769.19
Daugava	90016.35	65243.84	84673.75
Douro	5976.2	4927.85	6246.38
East	27492.49	20113.16	24596.89
East Aegean Isl.	34610.83	26535.35	35300.65
East Alps	19458.29	14804.26	17533.57
East Estonia	209884.3	149242.7	194755.4
Ebro	10389.35	7651.07	9488.49
Eider	16927.19	14441	18998.02
NorthWest (IRL)	29635.62	21111.87	28040.66
SouthEast (IRL)	17801.32	13044.88	15918.78
SouthWest (IRL)	25560.07	19687.9	22561.76
Elbe	14798.8	14634.21	14864.56
Ems	11503.52	9077.94	12087.41
Epirus	62972.73	44565.24	57802.38
Galician	7577.12	10076.31	11015.51
Gauja	85097.2	62241.85	81829.82
Guadalete	108552.6	86845.82	95319.81
Guadalquivir	10354.97	8171.41	10310.79
Guadiana	30343.24	24200.97	29947.16
Humber	4200.71	4288.23	4791.47
Jucar	62369.7	45018.51	59598.72
Jutland	97951.88	76286.99	99090.98
Koiva	174683.6	126308.2	167831
Lielupe	27931.63	20437.86	27057.53
Loire	8534.87	6739.51	8731.61
Meuse	29748.49	27182.81	34098.45
Middle Appenines	99271.99	70749.01	92255.13
Minho	19146.42	16069.94	18335.91
Mosel	7286.35	7438.16	8156.63
Neagh Bann	205231.3	172815.7	224487.9
Nemunas	25879.64	19022.83	24239.1
North Adriatic	4137.53	3478.07	3618.52
North Appenines	25072.62	18347.88	23849.15
Northumbria	5691.5	4086.45	5322.07
Oder	48647.18	41942.85	50848.9
Po	341890.5	249785.8	312877.8
Pregolya	55881.34	39944.84	50925.88
Rhine	50332.93	81619.22	56727.85
Rhone	227821.4	167250.4	207916.1
Sado	69124.67	49207.61	65474.47
Sardinia	136509.2	98717.84	133410.9
Scheldt	57182.19	52025.47	66752.12
Schlei	99574.47	85891.29	110036.7
Scotland	16234.26	13092.9	14483.33
Segura	53072.39	40389.02	49078.75
Seine	7304.05	5471.55	6808.58
Serchio	112073.4	89041.22	109417.7
Severn	7395.3	6507.67	7843.29
Shannon	145082.6	108867.8	131141.1
Sicily	30300.4	22493.97	29761.1
Solway	10647.91	7960.84	9868.28
South Appenines	51116.74	40234.28	48094.26
Tagus	21327.75	17297.27	22329.12

Appendix S6.3

River Basin	CF_{MEF}	CF_{LEF}	CF_{AEF}
Tagus West	14239.61	11768.61	15429.66
Thames	17163.26	13900.53	18400.34
Thessalia	61256.88	43359.92	56236.75
Thrace	6428.48	4893.35	6591.86
North West (UK)	37995.76	27511.53	35689.24
South East (UK)	8248.33	6560.34	8724.28
South West (UK)	6209.73	4819.06	6340.26
Venta	41660.18	29773.95	38963.36
Vistula	25094.47	18848.07	23941.3
Vouga	17714.87	12745.69	17183.27
Warnow	77766.29	60782.73	80799.21
Weser	9343.23	6970.55	9290.44
West Aegean Isl.	132319.1	95604.97	128383.8
Western	83681.68	63710.64	74354.74
Western Wales	8655.44	6378.17	8099.35
West Estonian	29431.2	23465.05	29570.41
West Macedonia	201875.2	149631.6	198417.3
West Sterea	137996.8	101321.2	127378.3
Zealand	23005.2	17595.17	23755.04
(b) Streams			
Adour	8440.98	5315.4	9149.19
Aegean Isl.	389.99	1071.59	908.21
Algarve	1788.33	1018.12	1835.26
Andalusia	653.09	839.98	847.07
Anglian	1550.61	1124.92	1804.22
Balearic Isl.	646.83	1058.24	1156.66
Basque County	1520.32	1052.99	1742.27
Black Sea	10548.58	6292.03	10744.91
Cantabrian	1865.64	1166.37	2019.37
Catalan	1088.5	1094.27	1494.27
Cavado	7217.81	4487.43	7748.62
Central Macedonia	29.04	1692.31	280.37
Corsica	1929.99	1176.61	2054.77
Cyprus	1155.47	659.97	1185.37
Danube	19385.12	14798.3	22693.85
Daugava	9239.01	5603.69	9834.79
Douro	11935.65	8637.77	13762.93
East	2934.67	1742.05	3079.58
East Aegean Isl.	5154.11	5480.35	6281.03
East Alps	4666.51	2920.46	5026.5
East Estonia	2440.27	1405.71	2522.08
East Sterea	1743.92	1241.77	2028.29
Ebro	9401.49	5747.17	10033.18
Eider	1751.22	1240.83	2030.46
NorthWest (IRL)	3641.08	2102.42	3768.98
SouthEast (IRL)	2874.8	1760.73	3072.93
SouthWest (IRL)	2318.94	1327.98	2385.32
Elbe	20997.42	14411.01	23894.87
Ems	3857.94	3560.75	5087.23
Epirus	2526.84	3058.55	2668.34
Galician	1487.95	977.05	1651.41
Gauja	3010.72	1822.47	3204.34
Guadalete	1390.68	883.24	1517.65
Guadalquivir	2748.31	2897.46	3775.33
Guadiana	3082.47	2418.58	3727.02
Humber	5007.17	4391.99	6235.13
Jucar	173.34	135.98	203.01
Jutland	1590.64	1038.52	1765.05
Koiva	2464.45	1464.31	2594.9
Lielupe	3184.86	2229.31	3647.98
Loire	8652.48	6053.77	9918.74
Meuse	3210.06	2336.09	3738.08
Middle Appeninnes	2148.72	1627.46	2560.86
Minho	8233	4908.95	8645.18
Minho Lima	1699.76	950.77	1723.99
Mosel	6639.63	4748.83	7731.17
Neagh Bann	2334.46	1550.8	2606.88
Nemunas	13919.56	9441.05	15578.94
North Adriatic	3509.38	1921.29	3494
North Appenines	2590.4	1847.89	2984.27

River Basin	CF_{MEF}	CF_{LEF}	CF_{AEF}
North East	663.32	787.33	1006.38
North Peloponese	175.36	1208.66	651.17
Northumbria	3288.18	2076.89	3571.6
Oder	8247.77	6463.69	10044.14
Po	7073.66	5190.26	8263.8
Pregolya	12244.87	8665.33	14069.28
Rhine	13361.98	9005.97	15043.3
Rhone	7703.75	4656.97	8161.5
Sado	2049.63	1608.73	2479.68
Sardinia	892.79	497.85	902.93
Scheldt	1668.95	1269.78	1989.36
Schlei	1378.44	944.86	1570.72
Scotland	3379.1	1915	3440.89
Segura	300.77	186.04	314.86
Seine	9391.68	6192.45	10446.71
Serchio	4620.84	4001.96	5907.75
Severn	3688.9	3231.78	4600.99
Shannon	3236.43	1912.63	3393.88
Sicily	1921.08	1255.2	2108.01
Solway	6698.67	4170.18	7199.76
South Appenines	1458.83	1145.62	1745
Tagus	8931.89	7031.33	10724.37
TagusWest	4187.73	3830.49	5352.46
Thames	2535.37	3381.47	3814.84
Thessalia	1142.69	1665.7	1840.77
Thrace	463.18	1676.63	965.83
North West (UK)	2410.45	2008.74	2936.98
South East (UK)	1623.67	1584.11	2141.91
South West (UK)	1588.87	1076.62	1790.6
Venta	5740.41	3510.9	6144.19
Vistula	14294.19	10302.78	16672.79
Vouga	3223.73	2294.83	3687.59
Warnow	1508.21	1050.32	1732.64
Weser	7548.92	5525.03	8891.64
West Aegean Isl.	541.46	1095.47	900.57
Western	1836.47	1045.82	1883.44
Western Wales	1426.63	850.4	1497.55
West Estonian	2508.69	1455.23	2602.8
West Macedonia	353.65	2752.17	861.59
West Sterea	4821.28	2920.21	5038.43
Zealand	993.29	688.5	1138.78

Appendix S6.3

Table S6.3.2 *River-basin specific normalization score (NS, m^3) based on the three effect models (marginal – MEF, linear – LEF, and average – AEF) for* ***(a)*** *lakes and* ***(b)*** *streams.*

River Basin	NS_{MEF}	NS_{LEF}	NS_{AEF}
(a) Lakes			
Adour	7.76E+13	5.66E+13	7.01E+13
Algarve	3.40E+12	2.43E+12	3.09E+12
Andalusia	1.51E+13	1.19E+13	1.33E+13
Anglian	3.13E+13	2.32E+13	3.04E+13
BlackSea	5.40E+12	6.53E+12	7.42E+12
Cantabrian	2.85E+12	2.24E+12	2.75E+12
Catalan	3.45E+13	2.61E+13	3.31E+13
Cavado	4.78E+11	3.64E+11	4.25E+11
Central Macedonia	1.63E+12	1.21E+12	1.64E+12
Corsica	5.88E+12	4.25E+12	5.75E+12
Danube	4.51E+14	3.68E+14	4.59E+14
Daugava	1.03E+14	7.50E+13	9.73E+13
Douro	2.57E+13	2.12E+13	2.69E+13
East	1.65E+13	1.21E+13	1.48E+13
East Aegean Isl.	1.17E+13	8.97E+12	1.19E+13
East Alps	3.84E+13	2.92E+13	3.46E+13
East Estonia	1.91E+13	1.36E+13	1.77E+13
Ebro	3.55E+13	2.61E+13	3.24E+13
Eider	8.14E+12	6.95E+12	9.14E+12
NorthWest (IRL)	7.84E+12	5.59E+12	7.42E+12
SouthEast (IRL)	2.36E+13	1.73E+13	2.11E+13
SouthWest (IRL)	2.88E+13	2.22E+13	2.55E+13
Elbe	1.14E+14	1.12E+14	1.14E+14
Ems	2.41E+13	1.90E+13	2.53E+13
Epirus	1.83E+13	1.30E+13	1.68E+13
Galician	1.90E+12	2.53E+12	2.77E+12
Gauja	1.70E+13	1.24E+13	1.63E+13
Guadalete	1.45E+13	1.16E+13	1.27E+13
Guadalquivir	2.14E+13	1.69E+13	2.13E+13
Guadiana	6.32E+13	5.04E+13	6.24E+13
Humber	1.12E+13	1.14E+13	1.28E+13
Jucar	4.33E+13	3.13E+13	4.14E+13
Jutland	2.79E+14	2.17E+14	2.82E+14
Koiva	3.80E+12	2.74E+12	3.65E+12
Lielupe	9.64E+12	7.05E+12	9.34E+12
Loire	1.05E+14	8.27E+13	1.07E+14
Meuse	2.87E+14	2.62E+14	3.29E+14
Middle Appeninnes	1.72E+14	1.23E+14	1.60E+14
Minho	1.39E+13	1.17E+13	1.33E+13
Mosel	5.52E+12	5.64E+12	6.18E+12
Neagh Bann	1.94E+14	1.63E+14	2.12E+14
Nemunas	2.62E+13	1.93E+13	2.46E+13
North Adriatic	2.17E+11	1.82E+11	1.89E+11
North Appeninnes	3.22E+13	2.36E+13	3.07E+13
Northumbria	4.15E+12	2.98E+12	3.88E+12
Oder	2.61E+14	2.25E+14	2.73E+14
Po	1.84E+15	1.35E+15	1.69E+15
Pregolya	2.72E+13	1.95E+13	2.48E+13
Rhine	9.31E+14	1.51E+15	1.05E+15
Rhone	2.17E+15	1.59E+15	1.98E+15
Sado	2.07E+13	1.47E+13	1.96E+13
Sardinia	6.43E+13	4.65E+13	6.29E+13
Scheldt	7.65E+14	6.96E+14	8.93E+14
Schlei	6.87E+13	5.93E+13	7.59E+13
Scotland	4.26E+13	3.44E+13	3.80E+13
Segura	2.19E+13	1.67E+13	2.03E+13
Seine	9.84E+13	7.37E+13	9.17E+13
Serchio	6.14E+12	4.88E+12	6.00E+12
Severn	1.90E+13	1.67E+13	2.02E+13
Shannon	2.23E+14	1.67E+14	2.01E+14
Solway	9.48E+12	7.09E+12	8.79E+12
South Appeninnes	1.31E+14	1.03E+14	1.23E+14
Tagus	3.92E+13	3.18E+13	4.10E+13
TagusWest	9.68E+12	8.00E+12	1.05E+13
Thames	3.68E+13	2.98E+13	3.95E+13

River Basin	NS_{MEF}	NS_{LEF}	NS_{AEF}
Thessalia	2.19E+13	1.55E+13	2.01E+13
Thrace	1.60E+12	1.21E+12	1.64E+12
NorthWest (UK)	7.62E+13	5.52E+13	7.16E+13
SouthEast (UK)	3.44E+12	2.73E+12	3.64E+12
SouthWest (UK)	6.94E+12	5.38E+12	7.08E+12
Venta	1.76E+13	1.26E+13	1.65E+13
Vistula	1.64E+14	1.23E+14	1.56E+14
Vouga	5.78E+12	4.16E+12	5.61E+12
Warnow	5.65E+13	4.42E+13	5.87E+13
Weser	2.40E+13	1.79E+13	2.38E+13
West Aegean Isl.	1.03E+13	7.41E+12	9.95E+12
Western	5.89E+13	4.48E+13	5.23E+13
Western Wales	7.56E+12	5.57E+12	7.07E+12
West Estonian	4.69E+12	3.74E+12	4.71E+12
West Macedonia	7.86E+13	5.82E+13	7.72E+13
West Sterea	3.53E+13	2.59E+13	3.26E+13
Zealand	6.15E+12	4.70E+12	6.35E+12
(b) Streams			
Adour	5.42E+13	3.41E+13	5.88E+13
Aegean Isl.	1.14E+10	3.14E+10	2.67E+10
Algarve	2.03E+11	1.16E+11	2.09E+11
Andalusia	2.88E+11	3.71E+11	3.74E+11
Anglian	2.05E+12	1.48E+12	2.38E+12
BlackSea	1.24E+12	7.38E+11	1.26E+12
Cantabrian	8.59E+11	5.37E+11	9.30E+11
Catalan	1.05E+12	1.05E+12	1.44E+12
Cavado	1.35E+12	8.36E+11	1.44E+12
Central Macedonia	1.07E+10	9.45E+11	1.24E+11
Corsica	7.90E+11	4.82E+11	8.41E+11
Danube	3.32E+14	2.54E+14	3.89E+14
Daugava	1.06E+13	6.44E+12	1.13E+13
Douro	5.14E+13	3.72E+13	5.92E+13
East	1.76E+12	1.05E+12	1.85E+12
East Aegean Isl.	1.74E+12	1.85E+12	2.12E+12
East Alps	9.21E+12	5.76E+12	9.92E+12
East Estonia	2.22E+11	1.28E+11	2.29E+11
East Sterea	1.06E+11	7.52E+10	1.23E+11
Ebro	3.21E+13	1.96E+13	3.43E+13
Eider	8.43E+11	5.97E+11	9.77E+11
NorthWest (IRL)	9.64E+11	5.57E+11	9.98E+11
SouthEast (IRL)	3.82E+12	2.34E+12	4.08E+12
SouthWest (IRL)	2.62E+12	1.50E+12	2.69E+12
Elbe	1.61E+14	1.11E+14	1.84E+14
Ems	8.09E+12	7.47E+12	1.07E+13
Epirus	7.35E+11	8.90E+11	7.76E+11
Galician	3.74E+11	2.45E+11	4.15E+11
Gauja	6.01E+11	3.64E+11	6.39E+11
Guadalete	1.85E+11	1.18E+11	2.02E+11
Guadalquivir	5.67E+12	5.98E+12	7.79E+12
Guadiana	6.42E+12	5.04E+12	7.77E+12
Humber	1.34E+13	1.17E+13	1.66E+13
Jucar	1.20E+11	9.45E+10	1.41E+11
Jutland	4.53E+12	2.95E+12	5.02E+12
Koiva	5.36E+10	3.18E+10	5.64E+10
Lielupe	1.10E+12	7.69E+11	1.26E+12
Loire	1.06E+14	7.43E+13	1.22E+14
Meuse	3.10E+13	2.25E+13	3.61E+13
Middle Appeninnes	3.73E+12	2.83E+12	4.45E+12
Minho	5.98E+12	3.57E+12	6.28E+12
MinhoLima	1.29E+11	7.24E+10	1.31E+11
Mosel	5.03E+12	3.60E+12	5.86E+12
Neagh Bann	2.21E+12	1.47E+12	2.47E+12
Nemunas	1.41E+13	9.57E+12	1.58E+13
North Adriatic	1.84E+11	1.01E+11	1.83E+11
North Appeninnes	3.33E+12	2.38E+12	3.84E+12
North East	5.11E+10	6.06E+10	7.75E+10
North Peloponnese	1.15E+10	7.94E+10	4.28E+10
Northumbria	2.40E+12	1.52E+12	2.61E+12
Oder	4.42E+13	3.47E+13	5.39E+13
Po	3.81E+13	2.80E+13	4.45E+13

Appendix S6.3

River Basin	NS_{MEF}	NS_{LEF}	NS_{AEF}
Pregolya	5.97E+12	4.22E+12	6.85E+12
Rhine	2.47E+14	1.67E+14	2.78E+14
Rhone	7.33E+13	4.43E+13	7.76E+13
Sado	6.13E+11	4.81E+11	7.41E+11
Sardinia	4.21E+11	2.35E+11	4.26E+11
Scheldt	2.23E+13	1.70E+13	2.66E+13
Schlei	9.51E+11	6.52E+11	1.08E+12
Scotland	8.87E+12	5.03E+12	9.03E+12
Segura	1.24E+11	7.68E+10	1.30E+11
Seine	1.27E+14	8.34E+13	1.41E+14
Serchio	2.53E+11	2.19E+11	3.24E+11
Severn	9.49E+12	8.32E+12	1.18E+13
Shannon	4.97E+12	2.94E+12	5.21E+12
Solway	5.96E+12	3.71E+12	6.41E+12
South Appeninnes	3.73E+12	2.93E+12	4.46E+12
Tagus	1.64E+13	1.29E+13	1.97E+13
TagusWest	2.85E+12	2.60E+12	3.64E+12
Thames	5.44E+12	7.25E+12	8.18E+12
Thessalia	4.09E+11	5.96E+11	6.59E+11
Thrace	1.15E+11	4.16E+11	2.40E+11
NorthWest (UK)	4.83E+12	4.03E+12	5.89E+12
SouthEast (UK)	6.77E+11	6.60E+11	8.93E+11
SouthWest (UK)	1.77E+12	1.20E+12	2.00E+12
Venta	2.42E+12	1.48E+12	2.59E+12
Vistula	9.32E+13	6.72E+13	1.09E+14
Vouga	1.05E+12	7.49E+11	1.20E+12
Warnow	1.10E+12	7.64E+11	1.26E+12
Weser	1.94E+13	1.42E+13	2.28E+13
West Aegean Isl.	4.20E+10	8.49E+10	6.98E+10
Western	1.29E+12	7.36E+11	1.33E+12
Western Wales	1.25E+12	7.43E+11	1.31E+12
West Estonian	4.00E+11	2.32E+11	4.15E+11
West Macedonia	1.38E+11	1.07E+12	3.35E+11
West Sterea	1.23E+12	7.48E+11	1.29E+12
Zealand	2.65E+11	1.84E+11	3.04E+11

Table S6.3.4 *Results of ANOVA performed in* $\log_{10}CF_{w,r}$ *transformed results.* R^2 *of the model is equal to 0.56. The relative contribution of freshwater and model type to the total variance is shown as* $\frac{SS_{effect}}{SS_{total}}$*. Kolmogorov-Smirnov normality test of residuals of the analysis of variance (ANOVA) showed a p value = 0.102 and the Levene test for homogeneity of variances showed a p values of 0.064 (homogeneity of freshwater type variances) and 0.407 (homogeneity of model type variances).*

	Degrees of freedom	**Sum of squares (SS)**	**Mean sum of squares**	**F value**	**P value**	$\frac{SS_{effect}}{SS_{total}}$
Model	5	136.55	27.31	130.71	<0.001	
Error	519	108.44	0.21			
Total	524	244.98				
Explained variable						
Freshwater	1	134.71	134.71	644.77	<0.001	0.55
Method	2	1.62	0.81	3.88	0.021	0.01
Method*Freshwater	2	0.21	0.11	0.50	0.605	<0.001

Appendix S6.4

Appendix S6.4 Isolation of fate and effect factor variability

In order to isolate the variability of CFs across river basins due to the fate factors, we calculated CFs To attain that, we calculated grid-specific CFs ($CF_{w,i}$) in each basin without variability in effect factors as

$$CF_{w,i} = \sum_j FF_{i \to w,j} \quad \text{(S6.4.1)}$$

where $FF_{i \to w,j}$ is the partial fate factor of emitting grid *i* to freshwater type *w* receiving grid *j*, namely the residence time of P in freshwater w emitting to grid *i*. Likewise, we calculated grid-specific CFs in each basin without variabily in fate factors as

$$CF_{w,i} = \overline{EF_{w,\mathrm{j}}} \quad \text{(S6.4.2)}$$

where $\overline{EF_{w,\mathrm{j}}}$ is the mean effect of grid *i* on species in freshwater *w* in receiving grids *j*. River basin CFs ($CF_{w,r}$) were calculated as the mean of grid CFs within basin similarly to that described in the main text for the analysis of variance (ANOVA).

Supporting information

Appendix S7.1. Maximum reported concentrations of NO_3 (Table S1) per invertebrate species in temperate lakes and streams. Maximum reported concentrations of total phosphorus are available in Table S5.2.2, chapter 5 of this thesis.

Table S7.1 *Maximum reported concentrations of NO_3 (mg $N{\cdot}L^{-1}$) per invertebrate species in temperate **(a)** lakes and **(b)** streams.*

Species	Max NO_3
(a) Lake	
Argyroneta aquatica	0.03
Athripsodes aterrimus	0.03
Dugesia lugubris	0.03
Haliplus immaculatus	0.03
Limnephilus lunatus	0.03
Sigara distincta	0.03
Cyclops scutifer	0.035
Colurella adriatica	0.036
Colurella tesselata	0.036
Lecane clara	0.036
Lecane ligona	0.036
Lecane lunaris	0.036
Lecane mylacris	0.036
Lecane signifera	0.036
Stephanoceros fimbriatus	0.036
Trichotria tetractis	0.036
Cyclops strenuus	0.045
Heterocope appendiculata	0.045
Camptocercus rectirostris	0.05
Chydorus piger	0.05
Glyptotendipes barbipes	0.05
Jaera ischiosetosa	0.05
Limnephilus affinis	0.05
Sida crystallina	0.05
Simocephalus serrulatus	0.05
Corophium volutator	0.06
Gammarus zaddachi	0.06
Hydrobia ventrosa	0.06
Nereis diversicolor	0.06
Palaemonetes varians	0.06
Sigara stagnalis	0.06
Sphaeroma rugicauda	0.06
Arrenurus crassicaudatus	0.1
Caenis horaria	0.1
Clinotanypus nervosus	0.1
Cymatia coleoptrata	0.1
Dendrocoelum lacteum	0.1
Gammarus duebeni	0.1
Glossiphonia complanata	0.1
Glossiphonia heteroclita	0.1
Laccobius minutus	0.1
Mystacides longicornis	0.1
Neomysis integer	0.1
Oecetis ochracea	0.1
Proasellus meridianus	0.1
Stagnicola palustris	0.1
Stylaria lacustris	0.1
Amnicola limosus	0.101
Aplexa hypnorum	0.101
Cincinnatia cincinnatiensis	0.101
Fossaria dalli	0.101
Fossaria decampi	0.101
Fossaria exigua	0.101
Fossaria modicella	0.101
Fossaria parva	0.101
Fusconaia flava	0.101
Gyraulus circumstriatus	0.101
Gyraulus deflectus	0.101
Gyraulus parvus	0.101
Helisoma anceps	0.101
Helisoma campanulatum	0.101

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Species	Max NO_3
Helisoma trivolvis	0.101
Lampsilis siliquoidea	0.101
Lampsilis ventricosa	0.101
Physa gyrina	0.101
Physa integra	0.101
Physa jennessi	0.101
Physa winnipegensis	0.101
Planorbula armigera	0.101
Probythinella lacustris	0.101
Proptera alata	0.101
Sphaerium lacustre	0.101
Sphaerium nitidum	0.101
Sphaerium rhomboideum	0.101
Sphaerium striatinum	0.101
Stagnicola catascopium	0.101
Stagnicola elodes	0.101
Strophitus undulatus	0.101
Valvata sincera	0.101
Valvata tricarinata	0.101
Lecane mira	0.102
Bosmina berolinensis	0.105
Bosmina crassicornis	0.105
Bosmina obtusirostris	0.105
Daphnia cristata	0.105
Daphnia longiremis	0.105
Eurytemora lacustris	0.105
Mesocyclops oithonoides	0.105
Candona neglecta	0.128
Ilyocypris decipiens	0.128
Enallagma cyathigerum	0.141
Lecane stichaea	0.141
Lestes sponsa	0.141
Agrypnia pagetana	0.15
Alona quadrangularis	0.15
Arrenurus globator	0.15
Caenis luctuosa	0.15
Caenis robusta	0.15
Callicorixa praeusta	0.15
Cloeon dipterum	0.15
Cloeon simile	0.15
Corixa panzeri	0.15
Corixa punctata	0.15
Haliplus apicalis	0.15
Haliplus confinis	0.15
Helobdella stagnalis	0.15
Hesperocorixa linnaei	0.15
Hesperocorixa sahlbergi	0.15
Hydrodroma despiciens	0.15
Hygrotus inaequalis	0.15
Ischnura elegans	0.15
Nepa cinerea	0.15
Noterus clavicornis	0.15
Oecetis furva	0.15
Piona carnea	0.15
Polycelis tenuis	0.15
Rhantus frontalis	0.15
Sigara falleni	0.15
Sigara lateralis	0.15
Sigara striata	0.15
Theromyzon tessulatum	0.15
Phryganea striata	0.153
Eudiaptomus graciloides	0.16
Holopedium gibberum	0.16
Mesocyclops leukarti	0.16
Peracantha truncata	0.16
Polyphemus pediculus	0.16
Simocephalus vetulus	0.16
Keratella hiemalis	0.17
Alonella nana	0.181
Ilyocryptus sordidus	0.181
Acroperus harpae	0.215
Alona affinis	0.215
Arctodiaptomus alpinus	0.215
Cyclops abyssorum	0.215

Species	Max NO_3
Alona azorica	0.221
Alonella excisa	0.221
Attheyella trispinosa	0.221
Bradleycypris obliqua	0.221
Cypridopsis hartwigi	0.221
Graptoleberis testudinaria	0.221
Macrothrix groenlandica	0.221
Macrothrix rosea	0.221
Microcyclops rubellus	0.221
Scapholeberis rammneri	0.221
Arctodiaptomus bacillifer	0.231
Alona nuragica	0.239
Canthocamptus staphylinus	0.239
Diacyclops bicuspidatus	0.239
Diacyclops bisetosus	0.239
Estatheroporus gauthieri	0.239
Eucypris virens	0.239
Megacyclops gigas	0.239
Mixodiaptomus lilljeborgi	0.239
Paralimnocythere psammophila	0.239
Eudiaptomus gracilis	0.24
Scapholeberis mucronata	0.24
Alona costata	0.26
Alona tenuicaudis	0.26
Brachionus patulus	0.26
Filinia opoliensis	0.26
Hexarthra mira	0.26
Keratella valga	0.26
Lecane quadridentata	0.26
Agabus bipustulatus	0.283
Agabus congener	0.283
Agabus solieri	0.283
Allogamus antennatus	0.283
Allogamus auricollis	0.283
Allogamus uncatus	0.283
Apsectrotanypus trifascipennis	0.283
Arctocorisa carinata	0.283
Chaetocladius dentiforceps	0.283
Chironomus thummi	0.283
Corynoneura arctica	0.283
Corynoneura lacustris	0.283
Corynoneura lobata	0.283
Corynoneura scutellata	0.283
Cricotopus laricomalis	0.283
Endochironomus dispar	0.283
Erpobdella testacea	0.283
Helophorus glacialis	0.283
Hydroporus foveolatus	0.283
Hydroporus palustris	0.283
Limnephilus coenosus	0.283
Melampophylax mucoreus	0.283
Odontocerum albicorne	0.283
Paracladius alpicola	0.283
Paracladopelma camptolabis	0.283
Parakiefferiella coronata	0.283
Parakiefferiella triquetra	0.283
Paratanytarsus austriacus	0.283
Paratanytarsus laccophilus	0.283
Paratrichocladius nivalis	0.283
Paratrichocladius skirwithensis	0.283
Parorthocladius nudipennis	0.283
Pisidium oasertanum	0.283
Prodiamesa olivacea	0.283
Protanypus caudatus	0.283
Pseudodiamesa branickii	0.283
Pseudodiamesa nivosa	0.283
Radix peregra	0.283
Rheocricotopus effusus	0.283
Rhyacophila italica	0.283
Stictotarsus griseostriatus	0.283
Stilociadius montanus	0.283
Tanytarsus pallidicornis	0.283
Tvetenia calvescens	0.283
Acanthocyclops robustus	0.339

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Species	Max NO_3
Alona protzi	0.339
Alona rectangula	0.339
Alona weltneri	0.339
Alonella exigua	0.339
Anuraeopsis fissa	0.339
Ascomorpha ecaudis	0.339
Brachionus bidentata	0.339
Brachionus falcatus	0.339
Ceriodaphnia pulchella	0.339
Asplanchna girodi	0.386
Asplanchna seiboldi	0.386
Chydorus sphaericus	0.386
Cyclops vicinus	0.386
Daphnia magna	0.386
Daphnia pulex	0.386
Disparalona rostrata	0.386
Filinia terminalis	0.386
Notholca acuminata	0.386
Philodina megalotrocha	0.386
Polyarthra dolichoptera	0.386
Rotaria rotatoria	0.386
Synchaeta littoralis	0.386
Testudinella mucronata	0.386
Testudinella patina	0.386
Trichocerca elongata	0.386
Ancylus fluviatilis	0.4
Anisus vortex	0.4
Anisus vorticulus	0.4
Bathyomphalus contortus	0.4
Bithynia tentaculata	0.4
Ferrissia clessiniana	0.4
Gyraulus albus	0.4
Gyraulus crista	0.4
Hippeutis complanatus	0.4
Lymnaea auricularia	0.4
Lymnaea corvus	0.4
Lymnaea palustris	0.4
Lymnaea peregra	0.4
Lymnaea stagnalis	0.4
Neoplanorbis carinatus	0.4
Physa fontinalis	0.4
Physella acuta	0.4
Planorbarius corneus	0.4
Planorbis planorbis	0.4
Segmentina nitida	0.4
Valvata naticina	0.4
Valvata piscinalis	0.4
Viviparus contectus	0.4
Aeschna juncea	0.434
Limnephilus griseus	0.434
Palaemon modestus	0.513
Euchlanis dilatata	0.61
Notholca squamula	0.61
Brachionus angularis	0.655
Ploesoma hudsoni	0.655
Ceriodaphnia quadrangula	0.686
Mystacides azureus	0.686
Polyarthra remata	0.686
Asplanchna priodonta	0.745
Bosmina coregoni	0.745
Bosmina longirostris	0.745
Brachionus calyciflorus	0.745
Conochiloides natans	0.745
Conochilus hippocrepis	0.745
Conochilus unicornis	0.745
Daphnia cucullata	0.745
Daphnia longispina	0.745
Daphnia obtusa	0.745
Diaphanosoma brachyurum	0.745
Filinia longiseta	0.745
Gastropus hyptopus	0.745
Kellicottia longispina	0.745
Keratella cochlearis	0.745
Keratella quadrata	0.745

Species	Max NO_3
Leptodora kindtii	0.745
Polyarthra major	0.745
Polyarthra vulgaris	0.745
Pompholyx sulcata	0.745
Synchaeta pectinata	0.745
Trichocerca longiseta	0.745
Trichocerca similis	0.745
Tanypus kraatzi	0.762
Cephalodella gibboides	0.894
Cephalodella mus	0.894
Lecane bifurca	0.894
Lecane pyriformis	0.894
Lepadella elliptica	0.894
Leydigia acanthocercoides	0.894
Trichocerca vernalis	0.894
Dicrotendipes nervosus	1.139
Procladius choreus	1.199
Acanthocyclops bicuspidatus	1.2
Acanthocyclops languidus	1.2
Acanthocyclops vernalis	1.2
Aeschna cyanea	1.2
Ameletus inopinatus	1.2
Amphinemura triangularis	1.2
Brachionus urceolaris	1.2
Cephalodella gigantea	1.2
Codonella cratera	1.2
Keratella serrulata	1.2
Lecane aculeata	1.2
Lecane inermis	1.2
Leptophlebia vespertina	1.2
Leuctra aurita	1.2
Leuctra digitata	1.2
Leuctra fusca	1.2
Leuctra handlirschi	1.2
Leuctra nigra	1.2
Limnephilus rhombicus	1.2
Limnephilus stigma	1.2
Microcodon clavus	1.2
Nemoura cinerea	1.2
Nemurella pictetii	1.2
Oligotricha striata	1.2
Oxyurella tenuicaudis	1.2
Phryganea bipunctata	1.2
Plectrocnemia conspersa	1.2
Polycentropus flavomaculatus	1.2
Protonemura auberti	1.2
Protonemura hrabei	1.2
Pyrrhosoma nymphula	1.2
Sialis lutaria	1.2
Siphlonurus lacustris	1.2
Metacyclops mendocinus	1.222
Moina micrura	1.222
Notodiaptomus incompositus	1.222
Tropocyclops meridionalis	1.222
Cryptochironomus tentans	1.238
Anodonta woodiana woodiana	1.514
Lamprotula leai	1.514
Alona karelica	1.75
Ceriodaphnia megops	1.75
Chydorus gibbus	1.75
Dunhevedia crassa	1.75
Euchlanis triquetra	1.75
Notommata glyphura	1.75
Pseudochydorus globosus	1.75
Daphnia hyalina	2.872
Diaptomus glacialis	2.872
Endochironomus tendens	3.365
Cladotanytarsus mancus	3.428
Cricotopus flavocinctus	3.428
Cryptotendipes holsatus	3.428
Dicrotendipes tritomus	3.428
Polypedilum sordens	3.428
Psectrocladius limbatellus	3.428
Psectrocladius sordidellus	3.428

Appendix S7.1

Species	**Max NO_3**
Chironomus anthracinus	5.382
Cricotopus bicinctus	5.382
Tanypus punctipennis	5.382
Chironomus plumosus	5.728
Cricotopus sylvestris	5.728
Endochironomus albipennis	5.728
Nais communis	5.728
Nais variabilis	5.728
Parachironomus arcuatus	5.728
Paratanytarsus lauterborni	5.728
Polypedilum convictum	5.728
Chironomus aprilinus	8.465
Cryptochironomus defectus	8.465
Limnodrilus claparedianus	8.465
Limnodrilus hoffmeisteri	8.465
Limnodrilus profundicola	8.465
Polypedilum pedestre	8.465
Potamothrix hammoniensis	8.465
Psammoryctides albicola	8.465
Pseudosmittia forcipatus	8.465
Tubifex tubifex	8.465
Virgatanytarsus arduennensis	8.465
Asellus aquaticus	16.83

Appendix S7.2 Summary statistics of environmental concentrations

Table S7.2.1 *Average (α_c) and standard deviation (σ) of ^{10}log concentrations of NO_3 and total phosphorus (TP) in lake and stream monitoring stations in river basins reported by the European Environment Agency, EEA (2013b). The average and, in parenthesis, the standard deviation and number of monitoring stations are shown first for NO_3 and then for TP (separated by a slash). Units are mg P·L^{-1} or mg N·L^{-} and not available data are shown as n.a. The α_c and β_c (converted from the standard deviation σ as $\frac{\sigma\sqrt{3}}{\pi}$) were employed as described in equation 4 of the main text.*

Basin	Year	Lake	Stream
Adour	1985	n.a. / n.a.	0.16 (0.37, 88) / -0.68 (0.47, 4)
Black Sea	1985	n.a. / -1.55 (0.42, 5)	n.a. / n.a.
Danube	1985	-0.32 (0.28, 3) / n.a.	n.a. / n.a.
Daugava	1985	n.a. / n.a.	n.a. / -0.4 (0.42, 11)
Elbe	1985	n.a. / n.a.	0.39 (0.27, 28) / n.a.
Gauja	1985	n.a. / n.a.	n.a. / -0.54 (0.38, 8)
Guadalquivir	1985	n.a. / n.a.	n.a. / -0.54 (0.33, 7)
Humber	1985	0.34 (0.21, 2) / n.a.	0.99 (0.07, 3) / n.a.
Loire	1985	n.a. / -0.85 (0.32, 2)	n.a. / n.a.
North West (UK)	1985	-0.43 (0.33, 5) / n.a.	0.31 (0.41, 15) / n.a.
Northumbria	1985	n.a. / n.a.	0.02 (0.35, 4) / n.a.
Oder	1985	n.a. / n.a.	0.52 (0.09, 5) / n.a.
Pregolya	1985	n.a. / n.a.	n.a. / -0.17 (0.1, 3)
Rhine	1985	-1 (1.19, 2) / -1.46 (0.05, 2)	0.59 (0.16, 11) / n.a.
Rhone	1985	n.a. / n.a.	-0.01 (0.26, 33) / -0.02 (0.45, 9)
Scheldt	1985	n.a. / n.a.	0.69 (0.11, 18) / -0.06 (0.14, 3)
Seine	1985	0.11 (0.3, 2) / n.a.	0.53 (0.19, 14) / -0.48 (0.23, 3)
South Appenines	1985	n.a. / -1.6 (0.1, 3)	n.a. / n.a.
South East (Irl.)	1985	n.a. / n.a.	n.a. / -0.6 (0.18, 12)
South West (UK)	1985	n.a. / n.a.	0.3 (0.37, 4) / n.a.
Warnow	1985	n.a. / n.a.	0.39 (0.08, 4) / n.a.
Weser	1985	n.a. / n.a.	0.7 (0.11, 3) / n.a.
Adour	1986	n.a. / n.a.	0.25 (0.36, 88) / n.a.
Black Sea	1986	n.a. / -1.57 (0.43, 5)	n.a. / n.a.
Cantabrian	1986	n.a. / n.a.	n.a. / -1.2 (0.7, 2)
Danube	1986	-0.31 (0.29, 3) / n.a.	0.28 (0.19, 2) / n.a.
Daugava	1986	n.a. / n.a.	n.a. / -0.34 (0.5, 9)
Elbe	1986	n.a. / n.a.	0.48 (0.27, 29) / -0.64 (0.35, 7)
Gauja	1986	n.a. / n.a.	n.a. / -0.43 (0.19, 7)
Guadalquivir	1986	n.a. / n.a.	n.a. / -0.62 (0.32, 9)
Humber	1986	0.53 (0.05, 2) / n.a.	1 (0.09, 3) / n.a.
Meuse	1986	n.a. / n.a.	n.a. / 0.02 (0.23, 3)
North West (UK)	1986	-0.28 (0.31, 5) / n.a.	0.3 (0.4, 15) / n.a.
Northumbria	1986	n.a. / n.a.	0.01 (0.39, 4) / n.a.

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Basin	Year	Lake	Stream
Oder	1986	n.a. / n.a.	0.5 (0.17, 5) / n.a.
Po	1986	n.a. / -1.49 (0.02, 2)	n.a. / n.a.
Pregolya	1986	n.a. / n.a.	n.a. / 0.01 (0.49, 4)
Rhine	1986	-0.94 (1.1, 2) / n.a.	0.59 (0.18, 8) / n.a.
Rhone	1986	n.a. / n.a.	0.06 (0.23, 29) / -0.06 (0.44, 10)
Scheldt	1986	n.a. / n.a.	0.65 (0.12, 18) / n.a.
Seine	1986	0.41 (0.16, 2) / n.a.	0.48 (0.19, 12) / -0.38 (0.12, 3)
South Appenines	1986	n.a. / -1.49 (0.1, 2)	n.a. / n.a.
South East (Irl.)	1986	n.a. / n.a.	n.a. / -0.66 (0.18, 13)
South West (UK)	1986	n.a. / n.a.	0.32 (0.37, 4) / n.a.
Warnow	1986	n.a. / n.a.	0.25 (0.07, 4) / n.a.
Weser	1986	n.a. / n.a.	0.69 (0.07, 3) / n.a.
Adour	1987	n.a. / n.a.	0.19 (0.36, 98) / n.a.
Black Sea	1987	n.a. / -1.38 (0.41, 13)	n.a. / n.a.
Cantabrian	1987	n.a. / n.a.	n.a. / -0.46 (0.43, 58)
Danube	1987	-0.61 (0.46, 12) / n.a.	0.33 (0.25, 88) / n.a.
Daugava	1987	n.a. / n.a.	n.a. / -0.45 (0.26, 12)
Elbe	1987	n.a. / n.a.	0.53 (0.28, 30) / -0.79 (0.32, 24)
Gauja	1987	n.a. / n.a.	n.a. / -0.72 (0.2, 8)
Guadalquivir	1987	n.a. / n.a.	n.a. / -0.7 (0.37, 29)
Humber	1987	0.55 (0.04, 2) / n.a.	0.96 (0.08, 3) / n.a.
Middle Appenines	1987	n.a. / n.a.	n.a. / 0.02 (0.14, 3)
North West (UK)	1987	-0.42 (0.4, 4) / n.a.	0.3 (0.38, 14) / n.a.
Northumbria	1987	n.a. / n.a.	0.02 (0.32, 4) / n.a.
Oder	1987	n.a. / n.a.	0.5 (0.1, 4) / n.a.
Pregolya	1987	n.a. / n.a.	n.a. / -0.36 (0.08, 3)
Rhine	1987	-0.84 (1.05, 2) / -1.56 (0.09, 2)	0.59 (0.15, 13) / n.a.
Rhone	1987	n.a. / n.a.	0.01 (0.36, 50) / -0.29 (0.45, 15)
Scheldt	1987	n.a. / n.a.	0.62 (0.11, 18) / n.a.
Seine	1987	0.09 (0.31, 2) / n.a.	0.57 (0.2, 16) / -0.32 (0.17, 2)
Severn	1987	n.a. / n.a.	0.7 (0.68, 2) / n.a.
South Appenines	1987	n.a. / -1.5 (0.18, 2)	n.a. / n.a.
South West (Irl.)	1987	n.a. / n.a.	n.a. / -0.7 (0.15, 15)
South West (UK)	1987	n.a. / n.a.	0.31 (0.38, 4) / n.a.
Warnow	1987	n.a. / n.a.	0.35 (0.05, 4) / n.a.
Weser	1987	n.a. / n.a.	0.62 (0.1, 4) / n.a.
Adour	1988	n.a. / n.a.	0.23 (0.35, 99) / n.a.
Cantabrian	1988	n.a. / n.a.	n.a. / -0.49 (0.45, 62)
Cavado	1988	n.a. / -1.41 (0.38, 14)	n.a. / n.a.
Corsica	1988	n.a. / n.a.	-0.4 (0.2, 4) / n.a.
Danube	1988	-0.61 (0.34, 13) / n.a.	0.35 (0.25, 89) / n.a.
Douro	1988	n.a. / n.a.	n.a. / -0.43 (0.28, 17)
Elbe	1988	n.a. / n.a.	0.52 (0.24, 30) / -0.8 (0.3, 24)
Ems	1988	n.a. / n.a.	0.79 (0.17, 3) / -0.6 (0.07, 3)

Basin	Year	Lake	Stream
Gauja	1988	n.a. / n.a.	n.a. / -0.79 (0.22, 7)
Guadalquivir	1988	n.a. / n.a.	n.a. / -0.85 (0.37, 36)
Humber	1988	0.23 (0.75, 4) / n.a.	0.96 (0.11, 3) / n.a.
Jutland	1988	n.a. / -1.95 (0.49, 2)	n.a. / n.a.
Loire	1988	n.a. / n.a.	0.51 (0.34, 22) / n.a.
Meuse	1988	n.a. / n.a.	0.7 (0.27, 5) / -0.66 (0.57, 4)
Middle Appenines	1988	n.a. / n.a.	n.a. / -0.02 (0.23, 3)
North West (UK)	1988	-0.49 (0.35, 4) / n.a.	0.22 (0.37, 14) / n.a.
Northumbria	1988	n.a. / n.a.	-0.11 (0.41, 4) / n.a.
Oder	1988	n.a. / n.a.	0.51 (0.12, 5) / n.a.
Pregolya	1988	n.a. / n.a.	n.a. / -0.24 (0.28, 14)
Rhine	1988	-0.81 (0.95, 2) / -1.62 (0.02, 2)	0.63 (0.23, 41) / n.a.
Rhone	1988	n.a. / n.a.	-0.02 (0.36, 66) / -0.38 (0.38, 32)
Scheldt	1988	n.a. / n.a.	0.64 (0.15, 18) / n.a.
Seine	1988	0.28 (0.19, 2) / n.a.	0.62 (0.19, 15) / -0.29 (0.13, 4)
South West (Irl.)	1988	n.a. / n.a.	n.a. / -0.74 (0.15, 19)
South West (UK)	1988	n.a. / n.a.	0.32 (0.41, 4) / n.a.
Warnow	1988	n.a. / n.a.	0.39 (0.09, 4) / -0.4 (0.15, 3)
Weser	1988	n.a. / n.a.	0.71 (0.14, 14) / n.a.
Adour	1989	n.a. / n.a.	0.19 (0.39, 99) / n.a.
Cantabrian	1989	n.a. / n.a.	n.a. / -0.46 (0.5, 73)
Cavado	1989	n.a. / -1.36 (0.4, 13)	n.a. / n.a.
Corsica	1989	n.a. / n.a.	-0.4 (0.25, 7) / n.a.
Danube	1989	-0.77 (0.44, 12) / n.a.	0.32 (0.25, 90) / n.a.
Douro	1989	n.a. / n.a.	n.a. / -0.43 (0.35, 12)
East	1989	n.a. / n.a.	n.a. / -0.61 (0.25, 4)
Elbe	1989	n.a. / n.a.	0.48 (0.29, 29) / -0.63 (0.3, 24)
Ems	1989	n.a. / n.a.	0.59 (0.32, 4) / -0.46 (0.25, 26)
Gauja	1989	n.a. / n.a.	n.a. / -0.75 (0.33, 13)
Guadalquivir	1989	n.a. / n.a.	n.a. / -0.82 (0.5, 45)
Humber	1989	0.45 (0.44, 4) / n.a.	1.01 (0.09, 3) / -0.56 (0.3, 15)
Jutland	1989	-0.25 (0.56, 12) / -1.14 (0.38, 12)	n.a. / n.a.
Lielupe	1989	n.a. / n.a.	n.a. / -0.45 (0.39, 62)
Loire	1989	n.a. / n.a.	0.41 (0.28, 30) / n.a.
Meuse	1989	n.a. / n.a.	0.49 (0.25, 14) / n.a.
Middle Appenines	1989	n.a. / n.a.	n.a. / 0.18 (0.32, 8)
Neagh Bann	1989	n.a. / n.a.	-0.41 (0.28, 3) / n.a.
North East (UK)	1989	n.a. / n.a.	-0.2 (0.08, 3) / n.a.
North West (UK)	1989	-0.56 (0.37, 4) / n.a.	0.1 (0.49, 19) / n.a.
Northumbria	1989	n.a. / n.a.	0.04 (0.34, 4) / n.a.
Oder	1989	n.a. / n.a.	0.39 (0.27, 5) / -0.27 (0.31, 3)
Pregolya	1989	n.a. / n.a.	n.a. / -0.38 (0.2, 14)
Rhine	1989	-0.74 (0.81, 2) / -1.64 (0.05, 2)	0.54 (0.26, 69) / n.a.
Rhone	1989	n.a. / n.a.	-0.09 (0.36, 75) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
Scheldt	1989	n.a. / n.a.	0.56 (0.26, 20) / n.a.
Seine	1989	0.35 (0.11, 2) / n.a.	0.61 (0.17, 15) / -0.14 (0.14, 4)
South West (Irl.)	1989	n.a. / n.a.	n.a. / -0.75 (0.19, 27)
South West (UK)	1989	n.a. / n.a.	0.32 (0.41, 4) / n.a.
Tagus West	1989	n.a. / -1.68 (0.09, 2)	n.a. / n.a.
Warnow	1989	n.a. / n.a.	0.04 (0.15, 4) / n.a.
Weser	1989	n.a. / n.a.	0.7 (0.11, 14) / n.a.
Adour	1990	n.a. / -1.63 (0.32, 4)	0.15 (0.35, 98) / n.a.
Cantabrian	1990	n.a. / n.a.	0 (0.42, 6) / -0.73 (0.54, 66)
Cavado	1990	n.a. / -1.37 (0.41, 13)	n.a. / n.a.
Corsica	1990	n.a. / n.a.	-0.51 (0.08, 7) / n.a.
Danube	1990	-0.77 (0.44, 13) / n.a.	0.24 (0.26, 105) / n.a.
Douro	1990	n.a. / n.a.	0.11 (0.36, 26) / -0.44 (0.34, 17)
East	1990	n.a. / n.a.	n.a. / -0.67 (0.37, 4)
Ebro	1990	n.a. / n.a.	0.02 (0.38, 53) / n.a.
Elbe	1990	n.a. / n.a.	0.53 (0.26, 31) / -0.62 (0.37, 33)
Ems	1990	n.a. / n.a.	0.69 (0.2, 4) / -0.54 (0.28, 33)
Gauja	1990	n.a. / n.a.	n.a. / -0.58 (0.37, 15)
Guadalquivir	1990	n.a. / n.a.	0.24 (0.56, 13) / -0.68 (0.53, 40)
Guadiana	1990	n.a. / n.a.	0.25 (0.31, 8) / n.a.
Humber	1990	n.a. / -1.15 (0.43, 12)	1.02 (0.09, 3) / -0.55 (0.35, 20)
Jucar	1990	n.a. / n.a.	0.25 (0.68, 8) / n.a.
Jutland	1990	-0.14 (0.65, 12) / n.a.	n.a. / n.a.
Lielupe	1990	n.a. / n.a.	n.a. / -0.48 (0.38, 68)
Loire	1990	n.a. / n.a.	0.33 (0.44, 34) / n.a.
Meuse	1990	n.a. / n.a.	0.45 (0.27, 15) / n.a.
Middle Appenines	1990	n.a. / n.a.	n.a. / 0.21 (0.47, 13)
Minho	1990	n.a. / n.a.	-0.29 (0.15, 3) / n.a.
Neagh Bann	1990	n.a. / n.a.	0.46 (0.26, 3) / n.a.
North Adriatic	1990	n.a. / n.a.	-0.15 (0.24, 7) / -1.56 (0.31, 7)
North East (UK)	1990	n.a. / n.a.	0.58 (0.13, 3) / n.a.
North West (UK)	1990	-0.47 (0.27, 3) / n.a.	0.3 (0.35, 19) / n.a.
Northumbria	1990	n.a. / n.a.	-0.1 (0.47, 4) / n.a.
Oder	1990	n.a. / n.a.	0.39 (0.22, 5) / -0.4 (0.3, 4)
Pregolya	1990	n.a. / n.a.	n.a. / -0.47 (0.16, 15)
Rhine	1990	-0.93 (1.12, 2) / -1.4 (0.4, 3)	0.51 (0.27, 72) / n.a.
Rhone	1990	-0.28 (0.07, 3) / n.a.	-0.11 (0.39, 71) / n.a.
Scheldt	1990	n.a. / n.a.	0.47 (0.37, 29) / n.a.
Schlei	1990	n.a. / n.a.	0.47 (0.35, 2) / -0.73 (0.05, 2)
Scotland	1990	-0.73 (0.64, 5) / -1.74 (1.07, 5)	-0.72 (0.52, 11) / -1.77 (0.65, 9)
Seine	1990	0.47 (0.14, 2) / n.a.	0.52 (0.16, 15) / -0.21 (0.06, 4)
Solway	1990	n.a. / n.a.	-0.23 (0.44, 2) / n.a.
South West (Irl.)	1990	n.a. / n.a.	n.a. / -0.82 (0.17, 27)
South West (UK)	1990	n.a. / n.a.	0.32 (0.38, 4) / n.a.

Basin	Year	Lake	Stream
Tagus	1990	n.a. / n.a.	0.13 (0.35, 28) / n.a.
Tagus West	1990	n.a. / -1.85 (0.04, 2)	n.a. / n.a.
Warnow	1990	n.a. / n.a.	0.27 (0.06, 4) / n.a.
Weser	1990	n.a. / n.a.	0.7 (0.1, 15) / n.a.
Adour	1991	n.a. / n.a.	0.2 (0.38, 98) / n.a.
Cantabrian	1991	n.a. / n.a.	0.02 (0.15, 6) / -0.69 (0.57, 74)
Corsica	1991	n.a. / n.a.	-0.38 (0.11, 7) / n.a.
Danube	1991	-0.65 (0.4, 17) / -1.46 (0.53, 18)	0.27 (0.26, 105) / n.a.
Douro	1991	n.a. / n.a.	0.11 (0.32, 26) / -0.45 (0.27, 29)
East	1991	n.a. / n.a.	n.a. / -0.69 (0.1, 4)
Ebro	1991	n.a. / n.a.	0.21 (0.38, 53) / n.a.
Elbe	1991	n.a. / n.a.	0.5 (0.27, 37) / -0.62 (0.28, 43)
Ems	1991	n.a. / n.a.	0.78 (0.19, 3) / -0.57 (0.23, 29)
Gauja	1991	n.a. / n.a.	n.a. / -0.64 (0.35, 15)
Guadalquivir	1991	n.a. / n.a.	0.2 (0.42, 13) / -0.83 (0.44, 52)
Guadiana	1991	n.a. / n.a.	0.18 (0.38, 8) / n.a.
Humber	1991	n.a. / -1.23 (0.39, 12)	1.03 (0.06, 3) / -0.54 (0.41, 24)
Jucar	1991	n.a. / n.a.	0.3 (0.36, 16) / n.a.
Jutland	1991	-0.16 (0.63, 12) / n.a.	n.a. / n.a.
Lielupe	1991	n.a. / n.a.	n.a. / -0.54 (0.35, 84)
Loire	1991	n.a. / -1.74 (0.48, 2)	0.43 (0.32, 29) / -1.65 (0.34, 7)
Meuse	1991	n.a. / n.a.	0.44 (0.28, 19) / n.a.
Middle Appenines	1991	n.a. / n.a.	n.a. / 0.14 (0.3, 23)
Minho	1991	n.a. / n.a.	-0.19 (0.2, 3) / -0.73 (0, 2)
Mosel	1991	n.a. / n.a.	0.73 (0.01, 2) / -0.19 (0.3, 2)
Neagh Bann	1991	n.a. / n.a.	0.4 (0.25, 3) / n.a.
North Adriatic	1991	n.a. / n.a.	-0.15 (0.18, 7) / n.a.
North East (UK)	1991	n.a. / n.a.	0.5 (0.11, 3) / n.a.
North West (UK)	1991	-0.58 (0.36, 3) / n.a.	0.3 (0.36, 20) / n.a.
Northumbria	1991	n.a. / n.a.	0 (0.39, 4) / n.a.
Oder	1991	n.a. / n.a.	0.44 (0.17, 5) / -0.52 (0.26, 4)
Pregolya	1991	n.a. / n.a.	n.a. / -0.54 (0.19, 15)
Rhine	1991	-0.72 (0.9, 2) / -1.5 (0.36, 3)	0.49 (0.28, 83) / n.a.
Rhone	1991	n.a. / n.a.	-0.01 (0.36, 69) / n.a.
Scheldt	1991	n.a. / n.a.	0.56 (0.26, 29) / n.a.
Schlei	1991	n.a. / -1.73 (0.91, 5)	0.4 (0.38, 2) / n.a.
Scotland	1991	-0.68 (0.6, 5) / n.a.	-0.67 (0.53, 11) / n.a.
Seine	1991	0.42 (0.12, 2) / n.a.	0.59 (0.15, 15) / -0.36 (0.12, 4)
Solway	1991	n.a. / n.a.	-0.15 (0.43, 2) / n.a.
South West (Irl.)	1991	n.a. / n.a.	n.a. / -0.83 (0.18, 27)
South West (UK)	1991	n.a. / n.a.	0.39 (0.4, 4) / n.a.
Tagus	1991	n.a. / n.a.	-0.06 (0.72, 28) / n.a.
Tagus West	1991	n.a. / -1.68 (0.28, 3)	n.a. / n.a.
Warnow	1991	n.a. / n.a.	0.3 (0.07, 4) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
Weser	1991	n.a. / n.a.	0.66 (0.13, 15) / n.a.
Adour	1992	n.a. / n.a.	0.26 (0.35, 101) / n.a.
Black Sea	1992	n.a. / n.a.	0.41 (0.38, 4) / n.a.
Cantabrian	1992	n.a. / n.a.	0.05 (0.18, 6) / -0.7 (0.48, 124)
Corsica	1992	n.a. / n.a.	-0.66 (0.17, 7) / n.a.
Danube	1992	-0.67 (0.38, 18) / -1.53 (0.62, 18)	0.25 (0.33, 286) / n.a.
Daugava	1992	-0.06 (0.16, 5) / -1.2 (0.06, 5)	0.05 (0.15, 16) / -1.1 (0.26, 15)
Douro	1992	n.a. / n.a.	-0.07 (0.29, 26) / -0.67 (0.32, 69)
East	1992	n.a. / n.a.	n.a. / -0.73 (0.09, 4)
East Aegean Islands	1992	0.65 (0.59, 2) / n.a.	0.47 (0.39, 31) / n.a.
East Estonia	1992	-1.35 (0.7, 7) / -1.46 (0.32, 7)	-0.01 (0.4, 31) / -1.14 (0.31, 31)
Ebro	1992	n.a. / n.a.	0.27 (0.33, 52) / n.a.
Elbe	1992	n.a. / n.a.	0.55 (0.24, 71) / -0.66 (0.22, 52)
Ems	1992	n.a. / n.a.	0.78 (0.13, 3) / -0.51 (0.3, 38)
Gauja	1992	n.a. / n.a.	0 (0.04, 14) / -1.39 (0.16, 7)
Guadalquivir	1992	n.a. / n.a.	0.06 (0.37, 14) / -0.93 (0.48, 66)
Guadiana	1992	n.a. / n.a.	0.09 (0.31, 8) / n.a.
Humber	1992	-0.4 (0.28, 2) / -1.21 (0.33, 12)	1 (0.07, 3) / -0.57 (0.42, 24)
Jucar	1992	n.a. / n.a.	0.11 (0.51, 19) / n.a.
Jutland	1992	-0.14 (0.65, 12) / n.a.	n.a. / n.a.
Lielupe	1992	n.a. / n.a.	0.39 (0.18, 30) / -0.66 (0.57, 21)
Loire	1992	n.a. / n.a.	0.32 (0.38, 38) / -1.71 (0.3, 7)
Meuse	1992	n.a. / n.a.	0.5 (0.26, 19) / n.a.
Middle Appenines	1992	n.a. / n.a.	n.a. / 0.08 (0.26, 23)
Minho	1992	n.a. / n.a.	-0.16 (0.08, 3) / -0.79 (0.01, 2)
Mosel	1992	n.a. / n.a.	0.67 (0, 2) / -1.84 (0.63, 12)
Neagh Bann	1992	n.a. / n.a.	0.33 (0.28, 3) / n.a.
Nemunas	1992	n.a. / n.a.	0.02 (0.32, 42) / -0.86 (0.32, 38)
North Adriatic	1992	n.a. / n.a.	-0.19 (0.22, 7) / n.a.
North East (UK)	1992	n.a. / n.a.	0.42 (0.15, 3) / n.a.
North West (UK)	1992	-0.11 (0.28, 2) / n.a.	0.19 (0.5, 27) / n.a.
Northumbria	1992	n.a. / n.a.	0.03 (0.52, 4) / n.a.
Oder	1992	n.a. / n.a.	0.33 (0.29, 59) / -0.46 (0.11, 4)
Pregolya	1992	n.a. / n.a.	0.12 (0.16, 3) / -0.42 (0.07, 2)
Rhine	1992	n.a. / -1.42 (0.38, 2)	0.44 (0.3, 93) / n.a.
Rhone	1992	n.a. / n.a.	-0.06 (0.38, 77) / n.a.
Scheldt	1992	n.a. / n.a.	0.6 (0.21, 28) / n.a.
Schlei	1992	n.a. / n.a.	0.39 (0.43, 2) / n.a.
Scotland	1992	-0.73 (0.56, 6) / -1.72 (0.86, 6)	-0.69 (0.5, 12) / n.a.
Seine	1992	0.5 (0.12, 2) / n.a.	0.58 (0.14, 15) / -0.36 (0.42, 53)
Solway	1992	n.a. / n.a.	-0.27 (0.4, 2) / n.a.
South West (Irl.)	1992	n.a. / n.a.	n.a. / -0.93 (0.13, 27)
South West (UK)	1992	n.a. / n.a.	0.34 (0.4, 4) / n.a.
Tagus	1992	n.a. / n.a.	-0.05 (0.44, 26) / n.a.

Basin	Year	Lake	Stream
Venta	1992	n.a. / n.a.	0.11 (0.16, 16) / -1.15 (0.32, 12)
Vistula	1992	n.a. / n.a.	0.11 (0.26, 50) / -0.47 (0.45, 40)
Warnow	1992	n.a. / n.a.	0.35 (0.1, 4) / n.a.
Weser	1992	n.a. / n.a.	0.7 (0.11, 15) / n.a.
West Aegean	1992	n.a. / n.a.	0.81 (0.17, 5) / n.a.
West Estonian	1992	n.a. / n.a.	0.09 (0.3, 17) / -1.13 (0.22, 17)
Adour	1993	n.a. / n.a.	0.22 (0.35, 104) / -0.12 (0.01, 2)
Black Sea	1993	-0.41 (0.29, 2) / n.a.	0.16 (0.29, 5) / n.a.
Cantabrian	1993	n.a. / n.a.	-0.28 (0.38, 6) / -0.86 (0.55, 197)
Cavado	1993	n.a. / n.a.	n.a. / -1.21 (0.24, 16)
Corsica	1993	n.a. / n.a.	-0.44 (0.11, 7) / n.a.
Danube	1993	-0.66 (0.42, 18) / -1.59 (0.43, 17)	0.16 (0.33, 339) / -1.16 (0.3, 32)
Daugava	1993	0.12 (0.18, 5) / n.a.	0.09 (0.25, 16) / n.a.
Douro	1993	n.a. / n.a.	0.04 (0.18, 26) / -0.72 (0.28, 75)
East Aegean Islands	1993	n.a. / n.a.	0.03 (0.24, 35) / -0.7 (0.08, 3)
East Alps	1993	n.a. / -1.44 (0.19, 8)	n.a. / -1.47 (0.22, 14)
East Estonia	1993	-0.64 (0.34, 4) / n.a.	0.01 (0.34, 32) / n.a.
Ebro	1993	n.a. / n.a.	0.21 (0.32, 57) / n.a.
Elbe	1993	n.a. / n.a.	0.54 (0.24, 76) / -0.67 (0.2, 68)
Ems	1993	n.a. / n.a.	0.77 (0.08, 3) / n.a.
Epirus	1993	n.a. / n.a.	n.a. / -0.57 (0.36, 35)
Gauja	1993	n.a. / n.a.	-0.07 (0.07, 14) / -0.65 (0.31, 16)
Guadalquivir	1993	n.a. / n.a.	0 (0.33, 13) / n.a.
Guadiana	1993	n.a. / n.a.	0.19 (0.23, 7) / -0.76 (0.41, 58)
Humber	1993	-0.18 (0.06, 2) / -1.23 (0.35, 12)	1 (0.09, 3) / -0.57 (0.42, 24)
Jucar	1993	n.a. / n.a.	-1.23 (0.78, 8) / n.a.
Jutland	1993	-0.14 (0.7, 12) / n.a.	n.a. / n.a.
Lielupe	1993	n.a. / n.a.	0.33 (0.21, 31) / -0.75 (0.49, 100)
Loire	1993	n.a. / -1.93 (0.32, 2)	0.47 (0.36, 35) / -1.74 (0.19, 7)
Meuse	1993	n.a. / n.a.	0.48 (0.23, 20) / n.a.
Middle Appenines	1993	n.a. / n.a.	n.a. / 0.03 (0.32, 22)
Minho	1993	n.a. / n.a.	-0.22 (0.16, 3) / -0.87 (0.04, 2)
Mosel	1993	n.a. / n.a.	0.7 (0.09, 2) / -1.84 (0.77, 12)
Neagh Bann	1993	n.a. / n.a.	0.2 (0.24, 3) / n.a.
Nemunas	1993	-0.25 (0.61, 2) / -1.55 (0.21, 2)	0 (0.28, 43) / n.a.
North Adriatic	1993	n.a. / n.a.	-0.21 (0.23, 7) / n.a.
North East (UK)	1993	n.a. / n.a.	0.31 (0.1, 5) / n.a.
North West (UK)	1993	-0.29 (0.08, 3) / n.a.	0.13 (0.5, 27) / n.a.
Northumbria	1993	n.a. / n.a.	0.03 (0.36, 4) / -1.22 (0.26, 16)
Oder	1993	n.a. / n.a.	0.3 (0.26, 61) / -0.72 (0.13, 4)
Po	1993	-0.4 (0.67, 2) / -0.89 (0.24, 2)	n.a. / n.a.
Pregolya	1993	n.a. / n.a.	0.13 (0.18, 3) / -0.64 (0.17, 16)
Rhine	1993	-0.08 (0.54, 22) / -1.36 (0.38, 22)	0.4 (0.31, 98) / n.a.
Rhone	1993	n.a. / n.a.	-0.03 (0.37, 75) / -0.51 (0.06, 3)

Appendix S7.2

Basin	Year	Lake	Stream
Scheldt	1993	n.a. / n.a.	0.6 (0.19, 30) / n.a.
Schlei	1993	n.a. / n.a.	0.46 (0.38, 2) / n.a.
Scotland	1993	-0.73 (0.55, 6) / -1.73 (0.82, 6)	-0.66 (0.53, 12) / n.a.
Seine	1993	0.42 (0.18, 2) / n.a.	0.62 (0.15, 16) / -0.39 (0.44, 56)
Solway	1993	n.a. / n.a.	-0.32 (0.53, 2) / n.a.
South West (Irl.)	1993	n.a. / n.a.	n.a. / -0.92 (0.15, 30)
South West (UK)	1993	n.a. / n.a.	0.35 (0.42, 4) / n.a.
Tagus	1993	n.a. / n.a.	-0.1 (0.46, 27) / n.a.
Tagus West	1993	n.a. / -1.59 (0.13, 2)	n.a. / n.a.
Venta	1993	-0.63 (0.1, 2) / -1.49 (0.44, 2)	0.04 (0.26, 16) / n.a.
Vistula	1993	n.a. / n.a.	0.15 (0.23, 53) / n.a.
Warnow	1993	n.a. / n.a.	0.43 (0.09, 4) / n.a.
Weser	1993	n.a. / n.a.	0.7 (0.11, 16) / n.a.
West Aegean	1993	n.a. / n.a.	0.22 (0.45, 12) / n.a.
West Estonian	1993	n.a. / n.a.	0.03 (0.3, 18) / n.a.
Adour	1994	n.a. / n.a.	0.21 (0.36, 103) / -0.28 (0.13, 2)
Andalusia	1994	n.a. / n.a.	0.04 (0.38, 14) / n.a.
Black Sea	1994	-0.12 (0.17, 2) / n.a.	0.15 (0.16, 6) / n.a.
Cantabrian	1994	n.a. / n.a.	-0.34 (0.57, 17) / -0.89 (0.56, 260)
Catalan	1994	n.a. / n.a.	0.24 (0.29, 58) / n.a.
Central Macedonia	1994	n.a. / n.a.	n.a. / -1.18 (0.24, 16)
Corsica	1994	n.a. / n.a.	-0.32 (0.12, 7) / n.a.
Danube	1994	-0.58 (0.31, 18) / -1.44 (0.64, 20)	0.19 (0.36, 352) / -1.22 (0.29, 34)
Daugava	1994	-0.03 (0.23, 5) / n.a.	-0.03 (0.27, 16) / n.a.
Douro	1994	n.a. / n.a.	-0.04 (0.34, 45) / -0.97 (0.52, 20)
East Aegean Islands	1994	n.a. / n.a.	-0.06 (0.28, 33) / -0.72 (0.14, 4)
East Alps	1994	n.a. / -1.5 (0.32, 8)	n.a. / -1.42 (0.14, 15)
East Estonia	1994	-1.62 (1.03, 8) / n.a.	-0.05 (0.3, 34) / n.a.
Ebro	1994	n.a. / n.a.	0.17 (0.33, 92) / -0.83 (0.34, 7)
Elbe	1994	n.a. / n.a.	0.58 (0.25, 76) / -0.84 (0.19, 30)
Ems	1994	n.a. / n.a.	0.7 (0.12, 3) / n.a.
Epirus	1994	n.a. / n.a.	n.a. / -0.62 (0.3, 36)
Galician	1994	n.a. / n.a.	-0.16 (0.2, 4) / n.a.
Gauja	1994	n.a. / n.a.	-0.15 (0.23, 15) / -0.77 (0.24, 17)
Guadalquivir	1994	n.a. / n.a.	-0.09 (0.35, 33) / n.a.
Guadiana	1994	n.a. / n.a.	0.03 (0.35, 49) / -0.88 (0.42, 55)
Humber	1994	n.a. / -1.26 (0.35, 12)	0.97 (0.07, 3) / -0.52 (0.45, 32)
Jucar	1994	n.a. / n.a.	-0.46 (0.38, 53) / -1.07 (0.48, 14)
Jutland	1994	-0.17 (0.7, 12) / -0.65 (0.5, 2)	n.a. / n.a.
Lielupe	1994	n.a. / -1.58 (0.19, 3)	0.24 (0.18, 31) / -0.81 (0.48, 100)
Loire	1994	0.99 (0.57, 4) / -1.97 (0.39, 2)	0.54 (0.34, 36) / -1.82 (0.25, 7)
Meuse	1994	n.a. / n.a.	0.52 (0.21, 29) / -1.02 (0.2, 2)
Middle Appenines	1994	n.a. / n.a.	n.a. / -0.07 (0.31, 28)
Minho	1994	n.a. / n.a.	-0.8 (0.69, 7) / -0.8 (0.08, 2)

Basin	Year	Lake	Stream
Mosel	1994	n.a. / n.a.	0.73 (0.03, 2) / -1.76 (0.6, 12)
Neagh Bann	1994	n.a. / n.a.	0.14 (0.27, 3) / n.a.
Nemunas	1994	-0.76 (0.35, 3) / n.a.	-0.03 (0.28, 45) / n.a.
North Adriatic	1994	n.a. / n.a.	-0.16 (0.22, 7) / n.a.
North East (UK)	1994	n.a. / -0.92 (0.25, 2)	0.24 (0.14, 5) / n.a.
North West (UK)	1994	-0.28 (0.03, 3) / -1.54 (0.36, 2)	0.13 (0.5, 27) / n.a.
Northumbria	1994	n.a. / n.a.	-0.03 (0.4, 4) / -1.31 (0.39, 18)
Oder	1994	n.a. / n.a.	0.4 (0.22, 60) / -0.65 (0.46, 50)
Po	1994	-0.39 (0.64, 2) / n.a.	n.a. / n.a.
Pregolya	1994	n.a. / n.a.	0.12 (0.1, 4) / n.a.
Rhine	1994	-0.07 (0.41, 20) / -1.44 (0.48, 21)	0.39 (0.31, 101) / -0.59 (0.2, 15)
Rhone	1994	0.04 (0.67, 3) / n.a.	0.03 (0.41, 70) / -0.61 (0.15, 4)
Scheldt	1994	n.a. / n.a.	0.64 (0.17, 35) / n.a.
Schlei	1994	n.a. / n.a.	0.43 (0.45, 2) / n.a.
Scotland	1994	-0.61 (0.53, 5) / -1.74 (0.83, 7)	-0.7 (0.51, 12) / n.a.
Segura	1994	n.a. / n.a.	-0.13 (0.12, 6) / n.a.
Seine	1994	0.62 (0.76, 6) / n.a.	0.67 (0.17, 16) / -0.49 (0.44, 57)
Solway	1994	n.a. / n.a.	-0.33 (0.46, 2) / n.a.
South West (UK)	1994	n.a. / n.a.	0.35 (0.43, 4) / n.a.
Tagus	1994	n.a. / n.a.	-0.47 (0.46, 76) / n.a.
Tagus West	1994	n.a. / -1.55 (0.19, 3)	n.a. / n.a.
Venta	1994	-0.61 (0.25, 2) / n.a.	-0.07 (0.43, 18) / n.a.
Vistula	1994	n.a. / n.a.	0.11 (0.26, 53) / n.a.
Warnow	1994	n.a. / n.a.	0.55 (0.11, 4) / n.a.
Weser	1994	n.a. / n.a.	0.7 (0.11, 16) / n.a.
West Aegean	1994	n.a. / n.a.	0.74 (0.27, 6) / n.a.
West Estonian	1994	n.a. / n.a.	-0.02 (0.25, 18) / n.a.
Adour	1995	n.a. / n.a.	0.14 (0.38, 103) / -0.06 (0.14, 2)
Andalusia	1995	n.a. / n.a.	0.08 (0.43, 14) / n.a.
Black Sea	1995	-0.14 (0.43, 2) / n.a.	0.23 (0.31, 6) / n.a.
Cantabrian	1995	n.a. / n.a.	-0.32 (0.28, 4) / -0.52 (0.45, 7)
Catalan	1995	n.a. / n.a.	0.25 (0.28, 58) / n.a.
Central Macedonia	1995	n.a. / n.a.	n.a. / -1.27 (0.24, 16)
Corsica	1995	n.a. / n.a.	-0.55 (0.21, 7) / -0.84 (0.09, 2)
Danube	1995	-0.64 (0.32, 18) / -1.52 (0.54, 20)	0.21 (0.36, 368) / -1.27 (0.27, 34)
Daugava	1995	-0.08 (0.21, 5) / n.a.	-0.08 (0.22, 16) / -0.76 (0.36, 7)
Douro	1995	n.a. / n.a.	-0.03 (0.33, 45) / -0.83 (0.24, 78)
East Aegean Islands	1995	n.a. / n.a.	0.01 (0.29, 33) / -0.84 (0.07, 4)
East Alps	1995	n.a. / -1.36 (0.38, 8)	n.a. / n.a.
East Estonia	1995	-1.01 (0.53, 8) / n.a.	-0.05 (0.32, 34) / -1.59 (0.15, 15)
Ebro	1995	n.a. / n.a.	0.18 (0.38, 95) / -0.46 (0.91, 16)
Elbe	1995	-1.07 (0.46, 2) / -1.08 (0.18, 2)	0.57 (0.25, 78) / -0.92 (0.14, 30)
Ems	1995	n.a. / n.a.	0.66 (0.15, 3) / n.a.
Epirus	1995	n.a. / n.a.	n.a. / -0.66 (0.29, 37)

Appendix S7.2

Basin	Year	Lake	Stream
Galician	1995	n.a. / n.a.	n.a. / -1.88 (0.15, 4)
Gauja	1995	n.a. / n.a.	-0.04 (0.24, 15) / -0.75 (0.24, 30)
Guadalquivir	1995	n.a. / n.a.	-0.38 (0.39, 31) / n.a.
Guadiana	1995	n.a. / n.a.	0.05 (0.38, 48) / -0.89 (0.39, 63)
Humber	1995	n.a. / -1.29 (0.35, 12)	1 (0.08, 3) / -0.81 (0.49, 31)
Jucar	1995	n.a. / n.a.	-0.41 (0.44, 63) / n.a.
Jutland	1995	-0.25 (0.75, 12) / -0.62 (0.14, 2)	n.a. / n.a.
Lielupe	1995	n.a. / -1.74 (0.46, 3)	0.3 (0.12, 31) / -0.81 (0.44, 107)
Loire	1995	n.a. / -1.39 (0.7, 3)	0.52 (0.36, 35) / -1.68 (0.33, 7)
Meuse	1995	n.a. / n.a.	0.51 (0.19, 31) / -1.06 (0.11, 2)
Middle Appenines	1995	n.a. / n.a.	n.a. / -0.13 (0.37, 29)
Minho	1995	n.a. / n.a.	-0.76 (0.47, 4) / -1.5 (0.72, 4)
Mosel	1995	n.a. / n.a.	0.67 (0.06, 2) / -1.79 (0.65, 12)
Neagh Bann	1995	n.a. / n.a.	0.22 (0.26, 3) / n.a.
Nemunas	1995	-0.68 (0.37, 3) / n.a.	0 (0.27, 45) / n.a.
North Adriatic	1995	n.a. / n.a.	-0.16 (0.19, 7) / n.a.
North East (UK)	1995	n.a. / n.a.	0.35 (0.15, 5) / n.a.
North West (UK)	1995	-0.2 (0.12, 3) / -1.77 (0.08, 2)	0.09 (0.48, 28) / n.a.
Northumbria	1995	n.a. / n.a.	-0.05 (0.35, 4) / -1.42 (0.31, 19)
Oder	1995	n.a. / -0.93 (0.29, 2)	0.38 (0.23, 60) / -0.77 (0.43, 52)
Po	1995	-0.42 (0.68, 2) / n.a.	n.a. / n.a.
Pregolya	1995	n.a. / n.a.	0.19 (0.15, 4) / n.a.
Rhine	1995	-0.05 (0.38, 22) / -1.43 (0.46, 23)	0.4 (0.31, 108) / -0.71 (0.13, 16)
Rhone	1995	n.a. / n.a.	-0.08 (0.35, 75) / -0.66 (0.11, 4)
Scheldt	1995	n.a. / n.a.	0.64 (0.17, 36) / n.a.
Schlei	1995	n.a. / n.a.	0.36 (0.36, 2) / n.a.
Scotland	1995	-0.53 (0.48, 5) / -1.71 (0.88, 7)	-0.69 (0.53, 12) / n.a.
Segura	1995	n.a. / n.a.	-0.23 (0.44, 6) / n.a.
Seine	1995	0.46 (0.08, 2) / n.a.	0.66 (0.17, 29) / -0.55 (0.42, 56)
Solway	1995	n.a. / n.a.	-0.23 (0.47, 2) / n.a.
South West (UK)	1995	n.a. / n.a.	0.36 (0.43, 4) / n.a.
Tagus	1995	n.a. / n.a.	-0.69 (0.35, 37) / n.a.
Venta	1995	-0.65 (0.14, 2) / n.a.	-0.12 (0.38, 19) / n.a.
Vistula	1995	n.a. / n.a.	0.17 (0.23, 53) / n.a.
Warnow	1995	n.a. / n.a.	0.38 (0.07, 4) / n.a.
Weser	1995	n.a. / n.a.	0.67 (0.12, 16) / n.a.
West Aegean	1995	n.a. / n.a.	0.29 (0.44, 12) / n.a.
West Estonian	1995	n.a. / n.a.	-0.02 (0.28, 18) / n.a.
Adour	1996	n.a. / n.a.	0.15 (0.37, 103) / -0.13 (0.06, 2)
Andalusia	1996	n.a. / n.a.	0.33 (0.17, 14) / n.a.
Basque County	1996	n.a. / n.a.	n.a. / -0.63 (0.29, 10)
Black Sea	1996	0.24 (0.39, 2) / n.a.	0.33 (0.39, 6) / -1.17 (0.23, 5)
Cantabrian	1996	n.a. / n.a.	-0.1 (0.34, 23) / -0.98 (0.49, 332)
Catalan	1996	n.a. / n.a.	0.23 (0.39, 57) / n.a.

Basin	Year	Lake	Stream
Central Macedonia	1996	n.a. / n.a.	n.a. / -1.19 (0.28, 15)
Corsica	1996	n.a. / n.a.	-0.54 (0.18, 7) / -1 (0.39, 19)
Danube	1996	-0.57 (0.39, 18) / -1.59 (0.71, 20)	0.24 (0.38, 366) / -1.24 (0.34, 34)
Daugava	1996	-0.08 (0.22, 5) / n.a.	0 (0.11, 15) / -0.52 (0.3, 4)
Douro	1996	n.a. / n.a.	0.08 (0.34, 65) / -0.79 (0.26, 62)
East Aegean Islands	1996	n.a. / n.a.	0.19 (0.27, 32) / -0.82 (0.08, 4)
East Alps	1996	n.a. / -1.43 (0.26, 8)	n.a. / n.a.
East Estonia	1996	-1.03 (0.49, 8) / n.a.	0.03 (0.31, 34) / -1.57 (0.18, 15)
Ebro	1996	n.a. / n.a.	0.23 (0.36, 98) / n.a.
Eider	1996	n.a. / n.a.	n.a. / -1.28 (0.35, 22)
Elbe	1996	-1.13 (0.52, 4) / -1.28 (0.33, 4)	0.52 (0.27, 78) / -0.93 (0.19, 30)
Ems	1996	n.a. / n.a.	0.68 (0.19, 3) / n.a.
Epirus	1996	n.a. / n.a.	n.a. / -0.68 (0.27, 32)
Galician	1996	n.a. / n.a.	-0.05 (0.12, 4) / n.a.
Gauja	1996	n.a. / n.a.	0.04 (0.23, 15) / n.a.
Guadalete	1996	n.a. / n.a.	n.a. / -0.71 (0.29, 33)
Guadalquivir	1996	n.a. / n.a.	0.35 (0.42, 51) / n.a.
Guadiana	1996	n.a. / n.a.	0.35 (0.37, 56) / -0.7 (0.48, 63)
Humber	1996	-0.06 (0.12, 2) / -1.26 (0.25, 12)	1.06 (0.05, 3) / -0.67 (0.54, 31)
Jucar	1996	n.a. / n.a.	0.09 (0.5, 51) / -1.21 (0.23, 3)
Jutland	1996	-0.32 (0.59, 12) / n.a.	n.a. / n.a.
Lielupe	1996	n.a. / n.a.	0.19 (0.17, 31) / -0.81 (0.51, 109)
Loire	1996	n.a. / n.a.	0.44 (0.35, 32) / -1.62 (0.57, 7)
Meuse	1996	n.a. / -1.66 (0.18, 3)	0.45 (0.25, 33) / -1.05 (0.07, 2)
Middle Appenines	1996	n.a. / n.a.	n.a. / -0.11 (0.32, 29)
Minho	1996	n.a. / n.a.	-0.37 (0.21, 18) / n.a.
Minho Lima	1996	n.a. / n.a.	n.a. / -0.76 (0.1, 2)
Mosel	1996	n.a. / n.a.	0.65 (0.04, 2) / -1.72 (0.57, 12)
Neagh Bann	1996	n.a. / n.a.	0.35 (0.26, 3) / n.a.
Nemunas	1996	-1.2 (0.4, 3) / n.a.	-0.08 (0.26, 45) / n.a.
North Adriatic	1996	n.a. / n.a.	-0.17 (0.21, 7) / n.a.
North East (UK)	1996	n.a. / n.a.	0.51 (0.07, 5) / n.a.
North West (UK)	1996	0.03 (0.29, 4) / -1.59 (0.3, 2)	0.3 (0.46, 28) / n.a.
Northumbria	1996	n.a. / n.a.	0.06 (0.28, 4) / -1.33 (0.34, 19)
Oder	1996	n.a. / n.a.	0.36 (0.26, 68) / -0.66 (0.34, 61)
Po	1996	-0.41 (0.66, 2) / -0.94 (0.32, 2)	n.a. / -0.86 (0.07, 4)
Pregolya	1996	n.a. / n.a.	0.06 (0.11, 4) / n.a.
Rhine	1996	-0.16 (0.53, 22) / -1.49 (0.46, 23)	0.41 (0.3, 109) / -0.65 (0.14, 16)
Rhone	1996	n.a. / n.a.	-0.01 (0.42, 74) / -0.68 (0.19, 4)
Scheldt	1996	n.a. / n.a.	0.65 (0.21, 35) / n.a.
Schlei	1996	n.a. / n.a.	0.27 (0.41, 2) / n.a.
Scotland	1996	-0.41 (0.41, 5) / -1.77 (0.78, 7)	-0.6 (0.59, 12) / n.a.
Seine	1996	0.41 (0.12, 2) / n.a.	0.63 (0.18, 32) / -0.52 (0.35, 68)
Solway	1996	n.a. / n.a.	-0.09 (0.4, 2) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
South West (UK)	1996	n.a. / n.a.	0.42 (0.37, 4) / n.a.
Tagus	1996	n.a. / n.a.	-0.6 (0.33, 40) / n.a.
Thames	1996	n.a. / n.a.	n.a. / -0.45 (0.84, 2)
Venta	1996	-0.52 (0.01, 2) / n.a.	-0.06 (0.35, 19) / n.a.
Vistula	1996	n.a. / n.a.	0.13 (0.23, 62) / n.a.
Warnow	1996	n.a. / n.a.	0.16 (0.06, 4) / n.a.
Weser	1996	n.a. / n.a.	0.65 (0.11, 16) / n.a.
West Aegean	1996	n.a. / n.a.	0.46 (0.49, 13) / n.a.
West Estonian	1996	n.a. / n.a.	0.03 (0.22, 18) / n.a.
Adour	1997	n.a. / n.a.	0.12 (0.39, 110) / -0.32 (0.21, 2)
Basque County	1997	n.a. / n.a.	-0.25 (0.42, 2) / n.a.
Black Sea	1997	n.a. / n.a.	0.49 (0.46, 4) / -1.16 (0.32, 7)
Cantabrian	1997	n.a. / n.a.	-0.28 (0.33, 22) / -1.01 (0.52, 335)
Central Macedonia	1997	n.a. / n.a.	n.a. / -1.19 (0.21, 15)
Corsica	1997	n.a. / n.a.	-0.66 (0.24, 7) / n.a.
Cyprus	1997	n.a. / n.a.	0.1 (0.67, 8) / -0.76 (1.6, 2)
Danube	1997	-0.69 (0.46, 18) / -1.55 (0.59, 20)	0.21 (0.36, 368) / -1.29 (0.32, 34)
Daugava	1997	n.a. / n.a.	0.06 (0.11, 15) / n.a.
Douro	1997	n.a. / n.a.	-0.06 (0.55, 48) / -0.8 (0.25, 78)
East	1997	n.a. / n.a.	0.17 (0.7, 4) / n.a.
East Aegean Islands	1997	n.a. / n.a.	0.08 (0.29, 34) / -0.89 (0.12, 4)
East Estonia	1997	-1.2 (0.77, 8) / -1.45 (0.45, 8)	0.04 (0.33, 34) / -1.61 (0.09, 15)
Ebro	1997	n.a. / n.a.	0.14 (0.53, 69) / n.a.
Elbe	1997	-0.92 (0.44, 8) / -1.3 (0.48, 8)	0.5 (0.27, 78) / -0.97 (0.15, 30)
Ems	1997	n.a. / n.a.	0.66 (0.12, 3) / -0.77 (0.37, 62)
Galician	1997	n.a. / n.a.	n.a. / -0.73 (0.37, 38)
Gauja	1997	n.a. / n.a.	0.01 (0.29, 15) / n.a.
Guadalete	1997	n.a. / n.a.	n.a. / -0.74 (0.3, 44)
Guadalquivir	1997	n.a. / n.a.	0.4 (0.6, 34) / n.a.
Guadiana	1997	n.a. / n.a.	0.09 (0.49, 11) / -0.84 (0.42, 102)
Humber	1997	-0.08 (0.06, 2) / -1.3 (0.3, 12)	1.03 (0.09, 3) / -0.82 (0.5, 31)
Jucar	1997	n.a. / n.a.	0.3 (0.53, 22) / n.a.
Jutland	1997	-0.32 (0.67, 12) / -0.51 (0.34, 2)	n.a. / n.a.
Lielupe	1997	n.a. / n.a.	0.28 (0.2, 31) / -0.82 (0.46, 114)
Loire	1997	n.a. / n.a.	0.46 (0.34, 38) / -1.93 (0.25, 6)
Meuse	1997	n.a. / -1.68 (0.15, 3)	0.5 (0.23, 34) / -1.04 (0.13, 2)
Middle Appenines	1997	n.a. / n.a.	n.a. / -0.09 (0.3, 28)
Minho	1997	n.a. / n.a.	-0.3 (0.17, 12) / n.a.
Minho Lima	1997	n.a. / n.a.	n.a. / -0.77 (0.02, 2)
Mosel	1997	n.a. / n.a.	0.77 (0.04, 2) / -1.76 (0.63, 12)
Neagh Bann	1997	n.a. / n.a.	0.41 (0.25, 4) / n.a.
Nemunas	1997	-1.01 (0.35, 3) / n.a.	-0.01 (0.32, 45) / n.a.
North Adriatic	1997	n.a. / n.a.	-0.27 (0.36, 6) / n.a.
North East (UK)	1997	n.a. / n.a.	0.5 (0.09, 5) / n.a.

Basin	Year	Lake	Stream
North West (Irl.)	1997	n.a. / n.a.	-0.89 (0.37, 3) / n.a.
North West (UK)	1997	-0.17 (0.2, 3) / n.a.	0.24 (0.5, 28) / -1.05 (0.15, 4)
Northumbria	1997	n.a. / n.a.	0.09 (0.33, 4) / -1.4 (0.36, 19)
Oder	1997	n.a. / n.a.	0.31 (0.25, 74) / -0.7 (0.37, 63)
Po	1997	-0.42 (0.65, 2) / -0.92 (0.33, 2)	n.a. / -0.87 (0.1, 4)
Pregolya	1997	n.a. / n.a.	0.15 (0.16, 4) / n.a.
Rhine	1997	-0.18 (0.47, 23) / -1.46 (0.41, 24)	0.4 (0.31, 113) / -0.68 (0.08, 16)
Rhone	1997	n.a. / n.a.	-0.02 (0.41, 110) / -0.74 (0.2, 4)
Scheldt	1997	n.a. / n.a.	0.62 (0.19, 37) / n.a.
Schlei	1997	n.a. / n.a.	0.32 (0.43, 2) / n.a.
Scotland	1997	-0.5 (0.37, 5) / -1.71 (0.74, 7)	-0.62 (0.54, 12) / n.a.
Seine	1997	n.a. / n.a.	0.64 (0.16, 43) / -0.48 (0.44, 72)
Shannon	1997	n.a. / n.a.	0.06 (0.29, 14) / n.a.
Solway	1997	n.a. / n.a.	-0.16 (0.53, 2) / n.a.
South East (Irl.)	1997	n.a. / n.a.	0.6 (0.18, 5) / n.a.
South West (Irl.)	1997	n.a. / n.a.	0.19 (0.46, 14) / n.a.
South West (UK)	1997	n.a. / n.a.	0.39 (0.39, 4) / n.a.
Tagus	1997	n.a. / n.a.	-0.32 (0.62, 70) / n.a.
Venta	1997	n.a. / n.a.	-0.1 (0.34, 19) / n.a.
Vistula	1997	n.a. / n.a.	0.12 (0.2, 64) / n.a.
Warnow	1997	n.a. / n.a.	0.15 (0.09, 4) / n.a.
Weser	1997	n.a. / n.a.	0.65 (0.1, 16) / n.a.
West Aegean	1997	n.a. / n.a.	-0.3 (1.12, 12) / n.a.
West Estonian	1997	n.a. / n.a.	0.07 (0.25, 18) / n.a.
Adour	1998	n.a. / n.a.	0.13 (0.43, 109) / -0.22 (0.09, 2)
Basque County	1998	n.a. / n.a.	-0.15 (0.23, 2) / n.a.
Black Sea	1998	n.a. / n.a.	0.34 (0.24, 8) / -0.96 (0.25, 7)
Cantabrian	1998	n.a. / n.a.	-0.4 (0.65, 17) / -0.98 (0.5, 335)
Corsica	1998	n.a. / n.a.	-0.67 (0.33, 7) / -1.22 (0.11, 16)
Cyprus	1998	n.a. / n.a.	-0.07 (0.74, 9) / n.a.
Danube	1998	-0.6 (0.34, 18) / -1.84 (0.54, 34)	0.19 (0.34, 378) / -1.27 (0.3, 34)
Daugava	1998	-0.35 (0.36, 5) / n.a.	-0.25 (0.09, 16) / n.a.
Douro	1998	n.a. / n.a.	-0.02 (0.47, 48) / -0.76 (0.26, 78)
East Aegean Islands	1998	n.a. / n.a.	0.05 (0.32, 43) / -0.74 (0.08, 3)
East Estonia	1998	-0.97 (0.44, 8) / -1.42 (0.27, 8)	0 (0.34, 34) / -1.38 (0.14, 15)
Ebro	1998	n.a. / n.a.	0.2 (0.45, 39) / n.a.
Elbe	1998	-0.96 (0.46, 9) / -1.02 (0.54, 9)	0.49 (0.26, 77) / -0.91 (0.17, 30)
Ems	1998	n.a. / n.a.	0.69 (0.14, 4) / -0.75 (0.3, 57)
Galician	1998	n.a. / n.a.	n.a. / -0.73 (0.33, 37)
Gauja	1998	n.a. / n.a.	-0.17 (0.27, 15) / n.a.
Guadalete	1998	n.a. / n.a.	n.a. / -0.8 (0.27, 51)
Guadalquivir	1998	n.a. / n.a.	0.38 (0.38, 35) / n.a.
Guadiana	1998	n.a. / n.a.	-0.08 (0.52, 10) / -0.87 (0.4, 109)
Humber	1998	0.46 (0.55, 3) / -1.28 (0.29, 12)	0.88 (0.26, 16) / -0.93 (0.4, 31)

Appendix S7.2

Basin	Year	Lake	Stream
Jucar	1998	n.a. / n.a.	0.3 (0.36, 33) / n.a.
Jutland	1998	-0.15 (0.68, 12) / -1.05 (0.63, 3)	n.a. / n.a.
Lielupe	1998	n.a. / n.a.	0.37 (0.24, 31) / -0.85 (0.44, 112)
Loire	1998	n.a. / n.a.	0.5 (0.34, 38) / -1.85 (0.44, 6)
Meuse	1998	n.a. / n.a.	0.55 (0.26, 40) / -1.04 (0.17, 2)
Middle Appenines	1998	n.a. / -1.66 (0.11, 3)	n.a. / n.a.
Minho	1998	n.a. / n.a.	-0.24 (0.26, 12) / -0.29 (0.39, 35)
Minho Lima	1998	n.a. / n.a.	n.a. / -0.84 (0.17, 2)
Mosel	1998	n.a. / n.a.	0.72 (0.06, 2) / -1.75 (0.57, 12)
Neagh Bann	1998	n.a. / n.a.	0.38 (0.32, 3) / n.a.
Nemunas	1998	-0.85 (0.37, 3) / n.a.	0.09 (0.32, 46) / n.a.
North Adriatic	1998	n.a. / n.a.	-0.15 (0.21, 6) / n.a.
North East (UK)	1998	n.a. / n.a.	0.41 (0.1, 5) / -1.07 (0.26, 4)
North West (UK)	1998	0.41 (0.81, 4) / -1.47 (0.22, 2)	0.22 (0.53, 28) / n.a.
Northumbria	1998	n.a. / n.a.	0.11 (0.3, 4) / -1.3 (0.26, 19)
Oder	1998	n.a. / n.a.	0.38 (0.25, 73) / -0.72 (0.39, 64)
Po	1998	-0.44 (0.65, 2) / -0.97 (0.38, 2)	n.a. / -0.88 (0.06, 4)
Pregolya	1998	n.a. / n.a.	0.25 (0.18, 4) / n.a.
Rhine	1998	-0.19 (0.49, 23) / -1.5 (0.45, 23)	0.4 (0.32, 115) / -0.7 (0.12, 16)
Rhone	1998	n.a. / n.a.	0 (0.38, 123) / -0.81 (0.18, 4)
Scheldt	1998	n.a. / n.a.	0.69 (0.17, 35) / n.a.
Schlei	1998	n.a. / n.a.	0.46 (0.36, 2) / n.a.
Scotland	1998	-0.61 (0.33, 8) / -1.77 (0.69, 8)	-0.47 (0.51, 12) / n.a.
Seine	1998	n.a. / n.a.	0.66 (0.16, 51) / -0.58 (0.35, 73)
Shannon	1998	n.a. / n.a.	n.a. / -1.01 (0.25, 2)
Solway	1998	n.a. / n.a.	-0.05 (0.35, 2) / n.a.
South West (UK)	1998	n.a. / n.a.	0.36 (0.42, 4) / n.a.
Tagus	1998	n.a. / n.a.	-0.54 (0.5, 69) / n.a.
Venta	1998	-0.75 (0.32, 2) / n.a.	-0.21 (0.53, 19) / n.a.
Vistula	1998	n.a. / n.a.	0.19 (0.24, 65) / n.a.
Warnow	1998	n.a. / n.a.	0.46 (0.08, 4) / n.a.
Weser	1998	n.a. / n.a.	0.66 (0.1, 16) / n.a.
West Aegean	1998	n.a. / n.a.	-0.44 (0.45, 18) / n.a.
West Estonian	1998	n.a. / n.a.	0.13 (0.27, 18) / n.a.
Adour	1999	n.a. / n.a.	0.19 (0.41, 108) / -0.76 (0.18, 2)
Basque County	1999	n.a. / n.a.	-0.04 (0.21, 2) / n.a.
Black Sea	1999	0.1 (0.22, 4) / n.a.	0.26 (0.43, 8) / -0.72 (0.16, 5)
Cantabrian	1999	n.a. / n.a.	-0.17 (0.29, 15) / -1.49 (0.8, 8)
Catalan	1999	n.a. / n.a.	n.a. / -0.95 (0.46, 338)
Corsica	1999	n.a. / n.a.	-0.56 (0.21, 8) / -1.21 (0.17, 16)
Cyprus	1999	n.a. / n.a.	0.22 (0.78, 10) / n.a.
Danube	1999	-0.59 (0.31, 20) / -1.74 (0.52, 31)	0.2 (0.34, 380) / -1.24 (0.31, 34)
Daugava	1999	-0.42 (0.38, 5) / n.a.	-0.23 (0.12, 16) / n.a.
Douro	1999	n.a. / n.a.	0.04 (0.36, 47) / -0.81 (0.24, 78)

Basin	Year	Lake	Stream
East	1999	n.a. / n.a.	-0.35 (0.87, 4) / n.a.
East Aegean Islands	1999	-0.14 (0.41, 7) / n.a.	-0.02 (0.29, 43) / -0.81 (0.04, 3)
East Estonia	1999	-1.54 (0.81, 8) / -1.43 (0.3, 8)	-0.03 (0.31, 34) / -1.3 (0.09, 14)
Ebro	1999	n.a. / n.a.	0.09 (0.42, 70) / n.a.
Elbe	1999	-1.02 (0.39, 10) / -1.01 (0.47, 10)	0.5 (0.26, 78) / -0.9 (0.14, 30)
Ems	1999	n.a. / n.a.	0.61 (0.1, 3) / -0.69 (0.31, 61)
Galician	1999	n.a. / n.a.	n.a. / -0.76 (0.3, 37)
Gauja	1999	n.a. / n.a.	-0.28 (0.06, 14) / n.a.
Guadalquivir	1999	n.a. / n.a.	0.22 (0.41, 33) / -0.83 (0.25, 51)
Guadiana	1999	n.a. / n.a.	0.13 (0.34, 8) / -0.91 (0.4, 112)
Humber	1999	0.59 (0.67, 3) / -1.26 (0.36, 12)	0.89 (0.22, 19) / -0.2 (0.45, 2)
Jucar	1999	n.a. / n.a.	0.36 (0.33, 26) / n.a.
Jutland	1999	-0.23 (0.69, 12) / -1.09 (0.32, 7)	n.a. / n.a.
Lielupe	1999	n.a. / n.a.	0.26 (0.24, 31) / -0.84 (0.36, 122)
Loire	1999	n.a. / n.a.	0.53 (0.34, 38) / -1.85 (0.28, 6)
Meuse	1999	n.a. / n.a.	0.45 (0.22, 34) / -1.21 (0.35, 4)
Middle Appenines	1999	n.a. / -1.45 (0.15, 5)	n.a. / n.a.
Minho	1999	n.a. / n.a.	-0.16 (0.24, 10) / -0.35 (0.36, 34)
Minho Lima	1999	n.a. / n.a.	n.a. / -0.78 (0.01, 2)
Mosel	1999	n.a. / n.a.	0.72 (0.08, 2) / -1.65 (0.59, 12)
Neagh Bann	1999	n.a. / n.a.	0.2 (0.25, 4) / n.a.
Nemunas	1999	-1.51 (0.72, 4) / n.a.	-0.05 (0.28, 46) / -0.86 (0.28, 2)
North Adriatic	1999	n.a. / n.a.	-0.16 (0.3, 6) / n.a.
North East (UK)	1999	n.a. / n.a.	0.34 (0.15, 5) / -2.02 (1.47, 6)
North West (Irl.)	1999	n.a. / n.a.	-0.99 (0.92, 3) / n.a.
North West (UK)	1999	-0.39 (0.01, 3) / n.a.	0.16 (0.52, 28) / n.a.
Northumbria	1999	n.a. / n.a.	0 (0.38, 4) / -1.21 (0.15, 18)
Oder	1999	n.a. / -1.38 (0.23, 3)	0.38 (0.23, 74) / -0.72 (0.39, 61)
Po	1999	-0.4 (0.61, 2) / -0.99 (0.4, 2)	n.a. / -0.93 (0.04, 4)
Pregolya	1999	n.a. / n.a.	0.15 (0.2, 4) / n.a.
Rhine	1999	-0.1 (0.39, 23) / -1.55 (0.45, 22)	0.34 (0.31, 119) / -0.75 (0.1, 16)
Rhone	1999	n.a. / n.a.	-0.09 (0.41, 130) / -0.78 (0.21, 4)
Scheldt	1999	n.a. / n.a.	0.69 (0.15, 35) / n.a.
Schlei	1999	-0.58 (0.29, 2) / -1.15 (0.04, 2)	0.33 (0.45, 2) / n.a.
Scotland	1999	-0.63 (0.38, 8) / -1.77 (0.62, 8)	-0.53 (0.4, 12) / n.a.
Seine	1999	n.a. / -1.18 (0.32, 2)	0.65 (0.19, 51) / -0.64 (0.4, 71)
Severn	1999	n.a. / n.a.	0.3 (0.12, 2) / n.a.
Shannon	1999	n.a. / n.a.	-0.07 (0.42, 2) / n.a.
Solway	1999	n.a. / n.a.	-0.15 (0.45, 2) / -1.52 (0.39, 2)
South East (Irl.)	1999	n.a. / n.a.	0.51 (0.2, 12) / n.a.
South West (Irl.)	1999	n.a. / n.a.	0.49 (0.13, 6) / n.a.
South West (UK)	1999	n.a. / -1.17 (0.56, 4)	0.26 (0.4, 4) / n.a.
Tagus	1999	n.a. / n.a.	-0.52 (0.43, 61) / n.a.
Thames	1999	n.a. / -1.69 (0.19, 6)	n.a. / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
Venta	1999	-0.51 (0.43, 4) / n.a.	-0.04 (0.24, 18) / n.a.
Vistula	1999	n.a. / -1.27 (0.19, 5)	0.1 (0.24, 65) / n.a.
Warnow	1999	n.a. / n.a.	0.4 (0.08, 4) / n.a.
Weser	1999	n.a. / n.a.	0.62 (0.11, 16) / n.a.
West Aegean	1999	n.a. / n.a.	-0.03 (0.34, 18) / n.a.
West Estonian	1999	n.a. / n.a.	0.02 (0.29, 18) / n.a.
Adour	2000	n.a. / n.a.	0.2 (0.38, 108) / -0.49 (0.05, 2)
Andalusia	2000	n.a. / n.a.	-0.27 (0.64, 9) / n.a.
Basque County	2000	n.a. / n.a.	-0.19 (0.07, 2) / n.a.
Black Sea	2000	-0.28 (0.31, 4) / n.a.	0.09 (0.5, 8) / n.a.
Cantabrian	2000	n.a. / n.a.	-0.17 (0.24, 36) / n.a.
Catalan	2000	n.a. / n.a.	n.a. / -0.98 (0.48, 338)
Central Macedonia	2000	n.a. / n.a.	0.09 (0.18, 6) / n.a.
Corsica	2000	n.a. / n.a.	-0.5 (0.14, 7) / -1.16 (0.16, 16)
Cyprus	2000	n.a. / n.a.	-0.05 (0.69, 10) / n.a.
Danube	2000	-0.55 (0.33, 20) / -1.75 (0.56, 31)	0.18 (0.35, 380) / -1.29 (0.25, 34)
Daugava	2000	-0.32 (0.51, 5) / n.a.	-0.09 (0.13, 16) / n.a.
Douro	2000	n.a. / n.a.	-0.04 (0.38, 67) / -0.79 (0.26, 78)
East	2000	n.a. / n.a.	-0.26 (0.84, 5) / n.a.
East Aegean Islands	2000	-0.4 (0.55, 7) / n.a.	0.09 (0.35, 44) / -0.79 (0.09, 3)
East Alps	2000	n.a. / n.a.	0.12 (0.25, 49) / -1.29 (0.29, 42)
East Estonia	2000	-1.26 (0.62, 7) / -1.38 (0.31, 8)	-0.03 (0.36, 34) / -1.35 (0.13, 14)
East Sterea	2000	n.a. / n.a.	0.31 (0.26, 5) / n.a.
Ebro	2000	n.a. / n.a.	0.16 (0.43, 96) / 0.71 (0.81, 2)
Elbe	2000	-0.94 (0.3, 10) / -1.12 (0.49, 10)	0.47 (0.26, 78) / -0.92 (0.16, 31)
Ems	2000	n.a. / n.a.	0.6 (0.09, 3) / -0.98 (0.31, 102)
Epirus	2000	n.a. / n.a.	-0.47 (0.22, 7) / -0.95 (0.26, 7)
Galician	2000	n.a. / n.a.	-0.02 (0.16, 4) / -0.82 (0.27, 92)
Gauja	2000	n.a. / n.a.	-0.12 (0.12, 14) / n.a.
Guadalquivir	2000	n.a. / n.a.	0.14 (0.47, 63) / -0.84 (0.22, 50)
Guadiana	2000	n.a. / n.a.	0.1 (0.45, 56) / -0.98 (0.39, 65)
Humber	2000	0.42 (0.69, 3) / -1.21 (0.27, 12)	0.88 (0.25, 15) / -0.81 (0.54, 31)
Jucar	2000	n.a. / n.a.	0.22 (0.37, 52) / n.a.
Jutland	2000	-0.27 (0.63, 12) / -1.09 (0.23, 4)	n.a. / n.a.
Lielupe	2000	n.a. / n.a.	0.35 (0.19, 31) / -0.89 (0.38, 125)
Loire	2000	n.a. / n.a.	0.54 (0.39, 97) / -1.79 (0.45, 7)
Meuse	2000	n.a. / n.a.	0.49 (0.23, 42) / -0.98 (0.09, 3)
Middle Appenines	2000	n.a. / -1.61 (0.21, 5)	0.27 (0.17, 9) / -0.97 (0.23, 9)
Minho	2000	n.a. / n.a.	-0.31 (0.24, 18) / -0.29 (0.34, 33)
Mosel	2000	n.a. / n.a.	0.68 (0.06, 2) / -0.83 (0.04, 2)
Neagh Bann	2000	n.a. / n.a.	-0.32 (0.36, 4) / -1.63 (0.49, 12)
Nemunas	2000	-1.82 (0.34, 4) / n.a.	-0.03 (0.33, 46) / -1.02 (0.29, 2)
North Adriatic	2000	n.a. / -1.26 (0.3, 3)	-0.18 (0.25, 7) / n.a.
North Appenines	2000	n.a. / n.a.	0.13 (0.15, 9) / -1.08 (0.84, 9)

Basin	Year	Lake	Stream
North East (UK)	2000	n.a. / n.a.	-0.3 (0.13, 5) / -0.68 (0.3, 2)
North Peloponese	2000	n.a. / n.a.	-0.03 (0.22, 5) / n.a.
North West (Irl.)	2000	n.a. / n.a.	-0.94 (0.77, 3) / n.a.
North West (UK)	2000	-0.28 (0.06, 5) / n.a.	-0.05 (0.71, 28) / n.a.
Northumbria	2000	n.a. / n.a.	n.a. / -1.22 (0.16, 18)
Oder	2000	n.a. / n.a.	0.32 (0.25, 74) / -0.73 (0.39, 62)
Po	2000	-0.37 (0.59, 2) / -0.99 (0.38, 2)	n.a. / -0.89 (0.09, 4)
Pregolya	2000	n.a. / n.a.	0.15 (0.2, 4) / n.a.
Rhine	2000	-0.16 (0.48, 24) / -1.57 (0.39, 24)	0.31 (0.31, 124) / -0.78 (0.1, 16)
Rhone	2000	n.a. / n.a.	0.03 (0.38, 135) / -0.71 (0.3, 4)
Scheldt	2000	-0.96 (1.39, 2) / -0.84 (0.28, 3)	0.71 (0.16, 38) / n.a.
Schlei	2000	-0.66 (0.32, 2) / -1.23 (0.02, 2)	0.26 (0.45, 2) / n.a.
Scotland	2000	-0.65 (0.41, 7) / -1.75 (0.67, 7)	-0.42 (0.3, 12) / n.a.
Segura	2000	n.a. / n.a.	-0.13 (0.44, 7) / n.a.
Seine	2000	n.a. / -1.37 (0.1, 2)	0.66 (0.17, 52) / -0.65 (0.33, 72)
Shannon	2000	n.a. / n.a.	-0.16 (0.31, 4) / n.a.
Solway	2000	n.a. / n.a.	-0.12 (0.4, 2) / n.a.
South East (Irl.)	2000	n.a. / n.a.	0.52 (0.19, 12) / n.a.
South West (Irl.)	2000	n.a. / n.a.	0.36 (0.18, 5) / n.a.
South West (UK)	2000	n.a. / -1.21 (0.54, 3)	0.32 (0.42, 4) / n.a.
Tagus	2000	n.a. / n.a.	0.08 (0.43, 78) / n.a.
Thessalia	2000	n.a. / n.a.	0.27 (0.17, 11) / n.a.
Thrace	2000	n.a. / n.a.	0.82 (0.33, 8) / n.a.
Venta	2000	-0.7 (0.55, 3) / -1.36 (0.16, 5)	-0.02 (0.19, 18) / n.a.
Vistula	2000	n.a. / n.a.	0.12 (0.24, 65) / n.a.
Warnow	2000	n.a. / n.a.	0.34 (0.06, 4) / n.a.
Weser	2000	n.a. / n.a.	0.6 (0.1, 16) / n.a.
West Aegean	2000	n.a. / n.a.	-0.01 (0.41, 19) / n.a.
West Estonian	2000	n.a. / n.a.	0.08 (0.28, 18) / n.a.
West Macedonia	2000	n.a. / n.a.	0.4 (0.2, 5) / n.a.
West Sterea	2000	n.a. / n.a.	-0.73 (0.22, 2) / n.a.
Adour	2001	n.a. / n.a.	0.2 (0.39, 109) / -0.67 (0.1, 2)
Andalusia	2001	n.a. / n.a.	0.03 (0.42, 14) / -0.95 (0.27, 7)
Basque County	2001	n.a. / n.a.	-0.19 (0.21, 2) / n.a.
Black Sea	2001	-0.75 (0.19, 2) / n.a.	0.01 (0.49, 8) / -1.56 (0.28, 5)
Cantabrian	2001	n.a. / n.a.	-0.1 (0.36, 29) / n.a.
Catalan	2001	n.a. / n.a.	0.08 (0.53, 58) / -1.03 (0.54, 302)
Central Macedonia	2001	n.a. / n.a.	0.18 (0.23, 7) / n.a.
Corsica	2001	n.a. / n.a.	-0.38 (0.1, 6) / -1.12 (0.19, 16)
Cyprus	2001	n.a. / n.a.	0.36 (0.03, 2) / -1.29 (0.42, 57)
Danube	2001	-0.6 (0.36, 20) / -1.88 (0.54, 41)	0.12 (0.34, 461) / -1.26 (0.28, 34)
Daugava	2001	-0.26 (0.22, 5) / n.a.	-0.13 (0.09, 16) / n.a.
Douro	2001	n.a. / n.a.	0 (0.45, 68) / -0.82 (0.26, 78)
East	2001	n.a. / n.a.	0.37 (0.17, 3) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
East Aegean Islands	2001	-0.45 (0.29, 7) / n.a.	-0.01 (0.3, 44) / -0.78 (0.04, 3)
East Alps	2001	n.a. / n.a.	-0.61 (0.32, 65) / n.a.
East Estonia	2001	-0.91 (0.31, 5) / -1.35 (0.11, 5)	-0.01 (0.38, 34) / -1.32 (0.13, 17)
East Sterea	2001	n.a. / n.a.	0.11 (0.61, 6) / n.a.
Ebro	2001	n.a. / n.a.	0.22 (0.38, 97) / -0.28 (0.39, 2)
Eider	2001	n.a. / n.a.	n.a. / 0.01 (0.38, 7)
Elbe	2001	-1.09 (0.31, 10) / -1.17 (0.51, 10)	0.46 (0.27, 78) / -0.94 (0.14, 31)
Ems	2001	n.a. / n.a.	0.7 (0.06, 3) / -0.97 (0.28, 109)
Epirus	2001	n.a. / n.a.	0.15 (0.08, 7) / n.a.
Galician	2001	n.a. / n.a.	0.05 (0.22, 4) / -0.79 (0.24, 78)
Gauja	2001	n.a. / n.a.	-0.22 (0.22, 17) / n.a.
Guadalquivir	2001	n.a. / n.a.	0.37 (0.4, 64) / -0.82 (0.23, 48)
Guadiana	2001	n.a. / n.a.	0.06 (0.44, 56) / -1.1 (0.38, 95)
Humber	2001	0.54 (0.82, 3) / -1.23 (0.3, 12)	0.88 (0.24, 14) / -0.83 (0.48, 31)
Jucar	2001	n.a. / n.a.	0.22 (0.37, 52) / -1.3 (0.55, 19)
Jutland	2001	-0.32 (0.66, 12) / n.a.	n.a. / n.a.
Lielupe	2001	n.a. / n.a.	0.39 (0.23, 31) / -0.94 (0.38, 125)
Loire	2001	n.a. / n.a.	0.46 (0.39, 85) / -1.99 (0.35, 7)
Meuse	2001	n.a. / n.a.	0.47 (0.22, 41) / -1.15 (0.23, 4)
Middle Appenines	2001	n.a. / -1.67 (0.21, 5)	-0.76 (0.4, 22) / n.a.
Minho	2001	n.a. / n.a.	-0.26 (0.21, 18) / -0.38 (0.29, 36)
Mosel	2001	n.a. / n.a.	0.67 (0.01, 2) / -0.8 (0.12, 2)
Neagh Bann	2001	n.a. / n.a.	-0.52 (0.34, 3) / -1.66 (0.53, 12)
Nemunas	2001	-1.35 (0.25, 4) / n.a.	0.01 (0.32, 46) / -1.71 (0.49, 2)
North Adriatic	2001	n.a. / -1.36 (0.2, 3)	-0.22 (0.21, 7) / n.a.
North Appenines	2001	n.a. / n.a.	-1.15 (0.85, 24) / n.a.
North East (UK)	2001	n.a. / n.a.	-0.34 (0.18, 5) / -0.68 (0.3, 2)
North Peloponese	2001	n.a. / n.a.	0.07 (0.42, 8) / n.a.
North West (Irl.)	2001	n.a. / n.a.	-0.77 (0.3, 5) / n.a.
North West (UK)	2001	-0.3 (0, 4) / n.a.	-0.03 (0.7, 28) / n.a.
Northumbria	2001	n.a. / n.a.	0.14 (0.22, 4) / -1.24 (0.25, 21)
Oder	2001	n.a. / n.a.	0.35 (0.24, 74) / -0.71 (0.39, 63)
Po	2001	-0.06 (0.58, 10) / -1.45 (0.35, 10)	-0.18 (0.77, 16) / -0.95 (0.17, 16)
Pregolya	2001	n.a. / n.a.	0.2 (0.15, 4) / n.a.
Rhine	2001	-0.12 (0.37, 24) / -1.63 (0.46, 23)	0.31 (0.3, 121) / -0.7 (0.15, 15)
Rhone	2001	n.a. / n.a.	-0.04 (0.34, 126) / -0.63 (0.32, 4)
Scheldt	2001	-0.15 (0.23, 3) / -0.6 (0.2, 3)	0.71 (0.16, 39) / n.a.
Schlei	2001	-0.87 (0.35, 2) / -1.19 (0.03, 2)	0.3 (0.4, 2) / n.a.
Scotland	2001	-0.73 (0.23, 7) / -1.74 (0.7, 7)	-0.58 (0.45, 12) / n.a.
Segura	2001	n.a. / n.a.	-0.35 (0.63, 7) / n.a.
Seine	2001	n.a. / n.a.	0.64 (0.19, 52) / -0.67 (0.29, 74)
Shannon	2001	n.a. / n.a.	-0.07 (0.25, 7) / n.a.
Solway	2001	n.a. / n.a.	-0.25 (0.46, 2) / n.a.
South Appenines	2001	n.a. / n.a.	-0.53 (0.44, 12) / -1.04 (0.84, 7)

Basin	Year	Lake	Stream
South East (Irl.)	2001	n.a. / n.a.	0.52 (0.2, 12) / n.a.
South West (Irl.)	2001	n.a. / n.a.	0.33 (0.41, 8) / n.a.
South West (UK)	2001	n.a. / n.a.	0.33 (0.43, 4) / n.a.
Tagus	2001	n.a. / n.a.	-0.01 (0.58, 99) / n.a.
Thessalia	2001	n.a. / n.a.	0.2 (0.39, 12) / n.a.
Thrace	2001	n.a. / n.a.	-0.13 (0.23, 8) / n.a.
Venta	2001	-0.46 (0.7, 4) / -1.36 (0.33, 4)	-0.09 (0.31, 21) / n.a.
Vistula	2001	n.a. / n.a.	0.07 (0.27, 63) / n.a.
Warnow	2001	n.a. / n.a.	0.34 (0.09, 4) / n.a.
Weser	2001	n.a. / n.a.	0.61 (0.1, 16) / n.a.
West Aegean	2001	n.a. / n.a.	-0.14 (0.36, 18) / n.a.
West Estonian	2001	n.a. / n.a.	0.11 (0.27, 18) / n.a.
West Macedonia	2001	n.a. / n.a.	0.1 (0.17, 6) / n.a.
West Sterea	2001	n.a. / n.a.	-0.65 (0.36, 5) / n.a.
Adour	2002	n.a. / n.a.	0.14 (0.38, 109) / -0.56 (0.02, 2)
Andalusia	2002	n.a. / n.a.	-0.02 (0.5, 14) / -0.79 (0.3, 8)
Anglian	2002	n.a. / n.a.	n.a. / -0.71 (0.11, 2)
Basque County	2002	n.a. / n.a.	-0.12 (0.04, 2) / n.a.
Black Sea	2002	-0.4 (0.26, 4) / n.a.	0.23 (0.37, 8) / -1.41 (0.25, 8)
Cantabrian	2002	n.a. / n.a.	-0.14 (0.28, 25) / n.a.
Catalan	2002	n.a. / n.a.	0.2 (0.37, 60) / -0.43 (0.44, 47)
Central Macedonia	2002	n.a. / n.a.	0.38 (0.1, 6) / n.a.
Corsica	2002	n.a. / n.a.	-0.37 (0.15, 7) / -1.12 (0.23, 16)
Cyprus	2002	n.a. / n.a.	0.27 (0.53, 11) / -1.33 (0.39, 59)
Danube	2002	-0.65 (0.31, 21) / -1.84 (0.52, 43)	0.12 (0.34, 501) / -1.29 (0.29, 34)
Daugava	2002	-0.6 (0.46, 5) / -1.32 (0.23, 5)	-0.09 (0.14, 16) / n.a.
Douro	2002	n.a. / n.a.	-0.01 (0.4, 65) / -0.88 (0.25, 80)
East	2002	n.a. / n.a.	0.48 (0.13, 3) / n.a.
East Aegean Islands	2002	-0.71 (0.46, 7) / n.a.	-0.04 (0.31, 44) / -0.75 (0.08, 4)
East Alps	2002	n.a. / -1.81 (0.37, 18)	0.09 (0.33, 65) / n.a.
East Estonia	2002	-1 (0.4, 5) / -1.36 (0.08, 5)	-0.02 (0.38, 34) / -1.28 (0.14, 16)
East Sterea	2002	n.a. / n.a.	0.58 (0.25, 3) / -1.18 (0.66, 3)
Ebro	2002	n.a. / n.a.	0.17 (0.39, 114) / -0.08 (0.35, 4)
Elbe	2002	-0.91 (0.41, 10) / -1.16 (0.47, 10)	0.49 (0.27, 80) / -0.94 (0.13, 31)
Ems	2002	n.a. / n.a.	0.51 (0.27, 4) / -0.93 (0.35, 97)
Epirus	2002	n.a. / n.a.	0.19 (0.15, 7) / n.a.
Galician	2002	n.a. / n.a.	-0.19 (0.21, 4) / -0.81 (0.26, 40)
Gauja	2002	n.a. / n.a.	-0.15 (0.21, 16) / n.a.
Guadalquivir	2002	n.a. / n.a.	0.25 (0.42, 49) / -0.9 (0.22, 47)
Guadiana	2002	n.a. / n.a.	-0.16 (0.53, 56) / -0.91 (0.43, 113)
Humber	2002	-0.21 (0.3, 2) / -1.23 (0.35, 12)	0.68 (0.33, 29) / -0.8 (0.48, 31)
Jucar	2002	n.a. / n.a.	0.37 (0.38, 67) / -1.2 (0.51, 24)
Jutland	2002	-0.37 (0.69, 12) / -1.17 (0.51, 3)	n.a. / n.a.
Lielupe	2002	n.a. / n.a.	0.31 (0.2, 31) / -0.93 (0.42, 124)

Appendix S7.2

Basin	Year	Lake	Stream
Loire	2002	0.52 (0.48, 3) / n.a.	0.49 (0.32, 41) / -1.99 (0.46, 7)
Meuse	2002	n.a. / n.a.	0.44 (0.21, 41) / -1.06 (0.2, 4)
Middle Appenines	2002	n.a. / -1.12 (0.49, 9)	0 (0.32, 24) / n.a.
Minho	2002	n.a. / n.a.	-0.32 (0.3, 17) / -0.42 (0.35, 34)
Mosel	2002	n.a. / n.a.	0.73 (0.03, 2) / -0.83 (0.06, 2)
Neagh Bann	2002	n.a. / n.a.	-0.41 (0.3, 3) / -1.73 (0.49, 12)
Nemunas	2002	-1 (0.54, 4) / n.a.	0 (0.26, 46) / -1.6 (0.32, 2)
North Adriatic	2002	n.a. / n.a.	-0.2 (0.29, 7) / -0.84 (0.74, 28)
North Appenines	2002	n.a. / -1.29 (0.57, 12)	0.03 (0.31, 23) / n.a.
North East (UK)	2002	n.a. / n.a.	-0.23 (0.09, 5) / -0.68 (0.34, 2)
North Peloponese	2002	n.a. / n.a.	0.09 (0.46, 7) / -0.49 (0.54, 3)
North West (Irl.)	2002	n.a. / n.a.	-0.73 (0.4, 5) / n.a.
North West (UK)	2002	-0.46 (0.1, 3) / n.a.	0.01 (0.73, 28) / n.a.
Northumbria	2002	n.a. / n.a.	-0.09 (0.47, 11) / -0.97 (0.41, 4)
Oder	2002	n.a. / n.a.	0.34 (0.23, 74) / -0.75 (0.45, 63)
Po	2002	-0.43 (0.65, 2) / -1.56 (0.48, 47)	0.36 (0.04, 17) / -0.99 (0.03, 4)
Pregolya	2002	n.a. / n.a.	0.2 (0.2, 4) / n.a.
Rhine	2002	-0.22 (0.48, 20) / -1.61 (0.36, 19)	0.31 (0.3, 124) / -0.73 (0.09, 17)
Rhone	2002	n.a. / n.a.	0 (0.35, 130) / -0.9 (0.27, 17)
Scheldt	2002	-0.03 (0.11, 2) / -0.52 (0.09, 2)	0.68 (0.16, 40) / n.a.
Schlei	2002	-0.53 (0.35, 2) / -1.13 (0.01, 2)	0.34 (0.36, 2) / n.a.
Scotland	2002	-0.63 (0.48, 7) / -1.62 (0.86, 7)	-0.66 (0.54, 12) / n.a.
Segura	2002	n.a. / n.a.	-0.21 (0.43, 7) / n.a.
Seine	2002	n.a. / n.a.	0.66 (0.2, 50) / -0.72 (0.29, 72)
Severn	2002	n.a. / n.a.	0.41 (0.5, 9) / n.a.
Shannon	2002	n.a. / n.a.	-0.14 (0.3, 7) / n.a.
Sicily	2002	n.a. / -1.57 (0.35, 7)	n.a. / n.a.
Solway	2002	n.a. / n.a.	0.05 (0.52, 3) / n.a.
South Appenines	2002	n.a. / -3.02 (1.35, 3)	0.18 (0.63, 28) / n.a.
South East (Irl.)	2002	n.a. / n.a.	0.54 (0.17, 12) / n.a.
South East (UK)	2002	n.a. / n.a.	0.64 (0.28, 6) / n.a.
South West (Irl.)	2002	n.a. / n.a.	0.23 (0.42, 8) / n.a.
South West (UK)	2002	-0.17 (0.6, 7) / n.a.	0.58 (0.27, 24) / -0.69 (0.24, 4)
Tagus	2002	n.a. / n.a.	0.03 (0.54, 92) / -0.69 (0.63, 96)
Thames	2002	0.42 (0.73, 2) / n.a.	0.76 (0.1, 4) / n.a.
Thessalia	2002	n.a. / n.a.	0.31 (0.25, 13) / -0.37 (0.37, 13)
Thrace	2002	n.a. / n.a.	0.09 (0.33, 8) / -1.18 (0.44, 8)
Venta	2002	-0.94 (0.29, 4) / -1.37 (0.29, 4)	-0.06 (0.21, 22) / n.a.
Vistula	2002	n.a. / n.a.	0.11 (0.23, 65) / n.a.
Warnow	2002	n.a. / n.a.	0.46 (0.07, 4) / n.a.
Weser	2002	n.a. / n.a.	0.65 (0.12, 17) / n.a.
West Aegean	2002	n.a. / n.a.	-0.11 (0.29, 19) / n.a.
West Estonian	2002	n.a. / n.a.	0.03 (0.31, 18) / n.a.
West Macedonia	2002	n.a. / n.a.	0.16 (0.12, 6) / -1.03 (0.27, 6)

Basin	Year	Lake	Stream
West Sterea	2002	n.a. / n.a.	-0.5 (0.35, 4) / n.a.
Western Wales	2002	-0.87 (0.24, 2) / n.a.	0.18 (0.34, 12) / n.a.
Adour	2003	n.a. / n.a.	0.13 (0.38, 101) / -0.96 (0.23, 46)
Andalusia	2003	n.a. / n.a.	0.09 (0.35, 13) / -1.03 (0.47, 7)
Anglian	2003	-1.51 (0.21, 8) / -1.18 (0.3, 9)	0.87 (0.13, 17) / n.a.
Basque County	2003	n.a. / n.a.	-0.26 (0.19, 2) / -0.81 (0.7, 46)
Black Sea	2003	-0.06 (0.35, 4) / -0.55 (0.1, 2)	0.03 (0.46, 8) / -1.01 (0.76, 6)
Cantabrian	2003	n.a. / n.a.	-0.14 (0.28, 24) / n.a.
Catalan	2003	n.a. / n.a.	0.31 (0.35, 46) / -0.97 (0.56, 374)
Corsica	2003	n.a. / n.a.	-0.37 (0.28, 7) / -1.04 (0.21, 18)
Cyprus	2003	n.a. / n.a.	0.04 (0.65, 9) / -1.32 (0.42, 61)
Danube	2003	-0.46 (0.64, 40) / -1.64 (0.58, 62)	0.12 (0.36, 509) / -1.24 (0.28, 34)
Daugava	2003	-0.22 (0.26, 5) / -1.18 (0.19, 5)	-0.13 (0.15, 18) / n.a.
Douro	2003	n.a. / n.a.	0.04 (0.46, 79) / -0.84 (0.25, 80)
East Aegean Islands	2003	-0.6 (0.3, 7) / -1 (0.32, 2)	-0.05 (0.31, 44) / -0.32 (0.51, 23)
East Alps	2003	-0.68 (0.58, 12) / n.a.	0.12 (0.29, 73) / n.a.
East Estonia	2003	-1.04 (0.43, 5) / -1.35 (0.13, 5)	0 (0.36, 34) / -1.14 (0.14, 15)
Ebro	2003	n.a. / n.a.	0.13 (0.45, 108) / -0.17 (0.32, 3)
Elbe	2003	-1.24 (0.33, 10) / -1.2 (0.46, 10)	0.43 (0.3, 80) / -0.99 (0.16, 31)
Ems	2003	n.a. / n.a.	0.55 (0.06, 3) / -1.01 (0.41, 101)
Galician	2003	n.a. / n.a.	0.04 (0.17, 4) / -0.88 (0.28, 38)
Gauja	2003	n.a. / n.a.	-0.18 (0.24, 15) / n.a.
Guadalquivir	2003	n.a. / n.a.	0.25 (0.48, 51) / -0.98 (0.28, 51)
Guadiana	2003	n.a. / n.a.	0 (0.69, 54) / -0.99 (0.44, 86)
Humber	2003	-1.86 (0.57, 6) / -1.23 (0.35, 12)	0.71 (0.32, 36) / -0.74 (0.44, 31)
Jucar	2003	n.a. / n.a.	0.34 (0.38, 68) / -0.83 (0.29, 37)
Jutland	2003	-0.43 (0.67, 12) / n.a.	n.a. / n.a.
Lielupe	2003	n.a. / n.a.	0.29 (0.21, 31) / -0.96 (0.43, 128)
Loire	2003	n.a. / n.a.	0.48 (0.3, 38) / -1.75 (0.46, 8)
Meuse	2003	n.a. / n.a.	0.38 (0.23, 35) / -1.09 (0.34, 4)
Middle Appenines	2003	0.12 (1.12, 12) / n.a.	0.08 (0.2, 37) / n.a.
Minho	2003	n.a. / n.a.	-0.24 (0.26, 18) / -0.48 (0.48, 40)
Mosel	2003	n.a. / n.a.	n.a. / -0.77 (0.04, 2)
Neagh Bann	2003	n.a. / -1.73 (0.29, 5)	-0.53 (0.38, 3) / -1.67 (0.57, 12)
Nemunas	2003	-1.19 (0.13, 4) / -1.44 (0.37, 6)	-0.07 (0.28, 46) / n.a.
North Adriatic	2003	-0.32 (0.18, 2) / -1.82 (0.19, 2)	-0.12 (0.21, 8) / -1.63 (0.35, 2)
North Appenines	2003	-0.33 (0.34, 7) / -1.16 (0.12, 3)	0.05 (0.29, 92) / n.a.
North East (UK)	2003	n.a. / n.a.	-0.34 (0.14, 5) / -1.11 (0.33, 8)
North Peloponese	2003	n.a. / n.a.	n.a. / -0.79 (0.72, 3)
North West (UK)	2003	-1.48 (0.63, 11) / -1.82 (0, 2)	0.01 (0.75, 26) / n.a.
Northumbria	2003	n.a. / n.a.	-0.22 (0.56, 8) / -0.53 (0.36, 3)
Oder	2003	n.a. / n.a.	0.3 (0.25, 74) / -0.76 (0.39, 65)
Po	2003	-0.35 (0.39, 59) / -1.58 (0.49, 60)	0.35 (0.18, 34) / -0.99 (0.13, 4)
Pregolya	2003	n.a. / n.a.	0.18 (0.13, 4) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
Rhine	2003	-0.23 (0.4, 24) / -1.64 (0.5, 23)	0.3 (0.3, 120) / -0.8 (0.11, 17)
Rhone	2003	n.a. / n.a.	-0.07 (0.35, 106) / -0.96 (0.25, 34)
Scheldt	2003	0.13 (0.19, 3) / -0.58 (0.22, 3)	0.63 (0.23, 40) / n.a.
Schlei	2003	-0.8 (0.28, 2) / -1.2 (0.02, 2)	0.17 (0.42, 2) / n.a.
Scotland	2003	-0.62 (0.3, 8) / -1.8 (0.63, 8)	-0.67 (0.46, 12) / n.a.
Segura	2003	n.a. / n.a.	-0.34 (0.67, 7) / n.a.
Seine	2003	n.a. / -1.25 (0.36, 12)	0.64 (0.18, 51) / -0.71 (0.32, 74)
Serchio	2003	n.a. / n.a.	-0.25 (0.24, 11) / -1.32 (0.16, 11)
Severn	2003	n.a. / n.a.	0.52 (0.43, 15) / n.a.
Sicily	2003	0.3 (0.55, 14) / n.a.	n.a. / n.a.
Solway	2003	n.a. / n.a.	0.17 (0.56, 4) / n.a.
South Appenines	2003	n.a. / n.a.	0.37 (0.56, 38) / n.a.
South East (UK)	2003	n.a. / n.a.	0.73 (0.23, 7) / n.a.
South West (UK)	2003	-2.07 (0.37, 8) / n.a.	0.56 (0.29, 21) / n.a.
Tagus	2003	n.a. / n.a.	0.05 (0.45, 92) / n.a.
Thames	2003	-1.58 (0.55, 3) / -1.52 (0.26, 2)	0.76 (0.25, 15) / n.a.
Thrace	2003	n.a. / n.a.	0.43 (0.18, 8) / n.a.
Venta	2003	-1.04 (0.62, 4) / -1.29 (0.36, 4)	-0.17 (0.29, 23) / n.a.
Vistula	2003	n.a. / n.a.	0.08 (0.23, 65) / n.a.
Warnow	2003	n.a. / n.a.	0.04 (0.06, 4) / n.a.
Weser	2003	n.a. / n.a.	0.58 (0.12, 17) / n.a.
West Aegean	2003	n.a. / n.a.	-0.17 (0.27, 19) / -0.81 (0.47, 12)
West Estonian	2003	n.a. / n.a.	0.02 (0.28, 18) / n.a.
Western Wales	2003	-2 (0.27, 2) / n.a.	0.21 (0.33, 12) / n.a.
Adour	2004	n.a. / n.a.	0.21 (0.38, 105) / -0.5 (0.04, 2)
Andalusia	2004	n.a. / n.a.	0.18 (0.3, 14) / 1.31 (0.16, 7)
Anglian	2004	n.a. / n.a.	0.94 (0.1, 17) / -0.27 (0.2, 3)
Basque County	2004	n.a. / n.a.	-0.18 (0.04, 2) / -0.85 (0.68, 43)
Black Sea	2004	-0.22 (0.39, 4) / -1.09 (0.65, 4)	0.14 (0.25, 8) / -1.58 (0.16, 5)
Cantabrian	2004	n.a. / n.a.	-0.07 (0.29, 25) / n.a.
Catalan	2004	n.a. / n.a.	0.38 (0.37, 46) / -1.15 (0.61, 514)
Corsica	2004	n.a. / n.a.	-0.34 (0.16, 5) / -1.08 (0.27, 19)
Cyprus	2004	n.a. / n.a.	n.a. / -0.71 (0.65, 31)
Danube	2004	-0.61 (0.5, 36) / -1.71 (0.57, 60)	0.09 (0.37, 643) / -1.3 (0.25, 34)
Daugava	2004	-0.88 (0.48, 12) / -1.51 (0.3, 12)	-0.18 (0.12, 19) / n.a.
Douro	2004	n.a. / n.a.	-0.08 (0.52, 86) / -0.84 (0.24, 76)
East	2004	n.a. / -1.4 (0.41, 3)	n.a. / n.a.
East Aegean Islands	2004	-0.1 (0.25, 7) / -2.1 (0.65, 16)	0.11 (0.3, 44) / -0.86 (0.04, 3)
East Alps	2004	n.a. / n.a.	0.15 (0.3, 72) / n.a.
East Estonia	2004	-1.81 (1.17, 10) / -1.48 (0.26, 11)	0.01 (0.39, 34) / -1.17 (0.13, 11)
Ebro	2004	n.a. / n.a.	0.23 (0.43, 107) / -0.57 (0.55, 4)
Elbe	2004	-1.12 (0.31, 10) / -1.21 (0.46, 10)	0.43 (0.29, 81) / -0.94 (0.14, 31)
Ems	2004	n.a. / n.a.	0.62 (0.06, 3) / -1.17 (0.38, 105)
Galician	2004	n.a. / n.a.	0.05 (0.2, 4) / -0.96 (0.25, 38)

Basin	Year	Lake	Stream
Gauja	2004	-0.77 (0.43, 5) / -1.51 (0.21, 5)	-0.15 (0.17, 11) / n.a.
Guadalquivir	2004	n.a. / n.a.	0.21 (0.51, 54) / -0.97 (0.59, 56)
Guadiana	2004	n.a. / n.a.	0.02 (0.55, 57) / -1.23 (0.47, 110)
Humber	2004	n.a. / -1.22 (0.33, 12)	0.74 (0.33, 36) / -0.83 (0.4, 31)
Jucar	2004	n.a. / n.a.	0.3 (0.36, 52) / -0.96 (0.37, 39)
Jutland	2004	-0.27 (0.61, 12) / n.a.	n.a. / n.a.
Lielupe	2004	-0.95 (0.02, 3) / -1.49 (0.21, 3)	0.44 (0.25, 31) / -1.03 (0.46, 131)
Loire	2004	n.a. / n.a.	0.48 (0.3, 38) / -1.84 (0.3, 8)
Meuse	2004	n.a. / n.a.	0.46 (0.19, 39) / -1.03 (0.21, 3)
Middle Appenines	2004	n.a. / n.a.	0.07 (0.3, 39) / n.a.
Minho	2004	n.a. / n.a.	-0.26 (0.25, 20) / -0.49 (0.49, 39)
Mosel	2004	n.a. / n.a.	0.72 (0, 2) / -0.86 (0.06, 2)
Neagh Bann	2004	n.a. / -1.72 (0.3, 4)	0.16 (0.3, 3) / -1.12 (0.39, 2)
Nemunas	2004	-1.03 (0.43, 4) / -3.12 (1.1, 8)	0.08 (0.28, 46) / n.a.
North Adriatic	2004	n.a. / n.a.	-0.05 (0.21, 8) / -1.43 (0.31, 2)
North Appenines	2004	n.a. / -1.35 (0.23, 3)	0.05 (0.31, 94) / n.a.
North East (UK)	2004	n.a. / n.a.	0.34 (0.12, 5) / -1.14 (0.47, 4)
North Peloponese	2004	n.a. / n.a.	n.a. / -0.74 (0.6, 3)
North West (Irl.)	2004	n.a. / -1.54 (0.39, 4)	n.a. / n.a.
North West (UK)	2004	-0.32 (0.11, 6) / -1.55 (0.2, 7)	0.16 (0.56, 26) / n.a.
Northumbria	2004	n.a. / n.a.	-0.29 (0.61, 8) / -0.6 (0.37, 3)
Oder	2004	n.a. / n.a.	0.32 (0.26, 67) / -0.78 (0.39, 65)
Po	2004	n.a. / -1.53 (0.52, 46)	0.4 (0.2, 34) / -1.01 (0.05, 4)
Rhine	2004	-0.18 (0.56, 25) / -1.65 (0.42, 24)	0.33 (0.32, 131) / -0.81 (0.12, 17)
Rhone	2004	n.a. / n.a.	0.03 (0.38, 110) / -0.7 (0.33, 72)
Scheldt	2004	0.01 (0.42, 3) / -0.58 (0.11, 3)	0.65 (0.17, 40) / n.a.
Schlei	2004	-0.78 (0.32, 2) / -1.24 (0, 2)	0.33 (0.36, 2) / n.a.
Scotland	2004	-0.57 (0.62, 2) / -1.77 (0.55, 8)	-0.62 (0.47, 12) / n.a.
Segura	2004	n.a. / n.a.	-0.37 (0.86, 7) / n.a.
Seine	2004	n.a. / -1.95 (0.8, 9)	0.67 (0.17, 51) / n.a.
Serchio	2004	n.a. / n.a.	-0.17 (0.34, 11) / n.a.
Severn	2004	n.a. / n.a.	0.57 (0.44, 15) / -0.8 (0.44, 3)
Solway	2004	n.a. / n.a.	0.16 (0.57, 4) / n.a.
South Appenines	2004	n.a. / n.a.	0.36 (0.61, 54) / n.a.
South East (Irl.)	2004	n.a. / n.a.	0.52 (0.21, 12) / n.a.
South East (UK)	2004	n.a. / n.a.	0.72 (0.18, 7) / n.a.
South West (UK)	2004	n.a. / n.a.	0.58 (0.29, 21) / n.a.
Tagus	2004	n.a. / n.a.	0.08 (0.49, 96) / n.a.
Thames	2004	n.a. / n.a.	0.78 (0.22, 15) / n.a.
Thrace	2004	n.a. / n.a.	0.21 (0.25, 8) / n.a.
Venta	2004	-0.82 (0.26, 6) / -1.52 (0.26, 6)	-0.02 (0.23, 19) / n.a.
Vistula	2004	n.a. / n.a.	0.1 (0.25, 52) / n.a.
Warnow	2004	n.a. / n.a.	0.2 (0.09, 4) / n.a.
Weser	2004	n.a. / n.a.	0.59 (0.12, 17) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
West Aegean	2004	n.a. / n.a.	-0.13 (0.29, 18) / n.a.
West Estonian	2004	n.a. / n.a.	0.13 (0.28, 18) / n.a.
Western	2004	n.a. / n.a.	-0.12 (0.29, 3) / n.a.
Western Wales	2004	n.a. / n.a.	0.24 (0.36, 12) / n.a.
Adour	2005	n.a. / n.a.	0.15 (0.39, 112) / -0.5 (0.11, 2)
Andalusia	2005	n.a. / n.a.	n.a. / -0.8 (0.42, 5)
Anglian	2005	n.a. / n.a.	0.83 (0.13, 17) / -0.76 (0.38, 7)
Basque County	2005	n.a. / n.a.	-0.01 (0.07, 2) / n.a.
Black Sea	2005	-0.31 (0.19, 2) / -1.76 (0.34, 2)	0.15 (0.31, 8) / -1.76 (0.26, 6)
Cantabrian	2005	n.a. / n.a.	-0.1 (0.27, 23) / n.a.
Catalan	2005	n.a. / n.a.	n.a. / -1.09 (0.73, 519)
Corsica	2005	n.a. / n.a.	-0.28 (0.2, 6) / -1.03 (0.22, 20)
Cyprus	2005	n.a. / n.a.	0.21 (0.34, 4) / -0.8 (0.5, 31)
Danube	2005	-0.56 (0.56, 36) / -1.65 (0.58, 60)	0.08 (0.36, 643) / -1.29 (0.28, 34)
Daugava	2005	-0.88 (0.61, 12) / -1.41 (0.3, 12)	-0.11 (0.08, 20) / n.a.
Douro	2005	n.a. / n.a.	-0.04 (0.48, 87) / -0.58 (1.16, 81)
East Aegean Islands	2005	-0.14 (0.26, 6) / -1.12 (0.43, 6)	0.03 (0.3, 43) / -0.83 (0.05, 3)
East Alps	2005	-0.57 (0.51, 19) / n.a.	0.12 (0.37, 74) / n.a.
East Estonia	2005	-1.52 (0.84, 11) / -1.38 (0.31, 11)	-0.04 (0.43, 34) / -1.18 (0.12, 11)
East Sterea	2005	n.a. / n.a.	n.a. / -0.8 (0.63, 55)
Ebro	2005	n.a. / n.a.	0.21 (0.38, 109) / -0.58 (0.78, 9)
Eider	2005	n.a. / n.a.	n.a. / -0.51 (0.58, 43)
Elbe	2005	-1.11 (0.28, 9) / -1.2 (0.39, 9)	0.42 (0.3, 81) / -0.99 (0.12, 31)
Ems	2005	n.a. / n.a.	0.58 (0.09, 3) / -1.12 (0.4, 112)
Galician	2005	n.a. / n.a.	0.06 (0.18, 4) / -0.97 (0.34, 96)
Gauja	2005	-0.64 (0.61, 5) / -1.55 (0.2, 5)	-0.15 (0.19, 11) / n.a.
Guadalquivir	2005	n.a. / n.a.	0.05 (0.54, 54) / -1.24 (0.33, 51)
Guadiana	2005	n.a. / n.a.	-0.06 (0.64, 56) / -1.41 (0.56, 92)
Humber	2005	n.a. / -1.34 (0.29, 12)	0.71 (0.34, 38) / -0.95 (0.3, 24)
Jucar	2005	n.a. / n.a.	0.29 (0.5, 81) / -1.18 (0.43, 36)
Jutland	2005	-0.37 (0.62, 12) / n.a.	n.a. / n.a.
Lielupe	2005	-1.08 (0.12, 2) / n.a.	0.34 (0.24, 24) / -1.04 (0.44, 132)
Loire	2005	n.a. / n.a.	0.44 (0.38, 96) / -1.74 (0.49, 8)
Meuse	2005	n.a. / n.a.	0.35 (0.27, 39) / -1.1 (0.17, 3)
Middle Appenines	2005	-0.46 (0.51, 13) / n.a.	0.14 (0.37, 36) / n.a.
Minho	2005	n.a. / n.a.	-0.23 (0.17, 21) / -0.43 (0.31, 39)
Mosel	2005	n.a. / n.a.	0.68 (0.03, 2) / -0.88 (0.02, 2)
Neagh Bann	2005	n.a. / n.a.	0.18 (0.31, 3) / -1.75 (0.64, 12)
Nemunas	2005	-1.03 (0.65, 6) / -1.62 (0.2, 7)	0.04 (0.26, 44) / -0.89 (0.55, 3)
North Adriatic	2005	-2.07 (0.13, 2) / n.a.	-0.13 (0.19, 8) / -1.47 (0.61, 2)
North Appenines	2005	-1.65 (0.91, 13) / -1.53 (0.13, 3)	0.07 (0.31, 93) / -0.68 (0.66, 95)
North East (UK)	2005	n.a. / n.a.	0.39 (0.11, 5) / -0.65 (1, 4)
North Peloponese	2005	n.a. / n.a.	n.a. / -0.96 (0.5, 8)
North West (UK)	2005	-0.3 (0.1, 6) / -1.52 (0.25, 7)	0.21 (0.5, 28) / n.a.

Basin	Year	Lake	Stream
Northumbria	2005	n.a. / n.a.	-0.14 (0.45, 12) / -0.94 (0.47, 9)
Oder	2005	n.a. / n.a.	0.32 (0.24, 73) / -0.78 (0.36, 70)
Po	2005	-0.34 (0.38, 59) / -1.6 (0.67, 59)	0.34 (0.17, 34) / n.a.
Pregolya	2005	n.a. / n.a.	0.2 (0.17, 4) / -1.01 (0.05, 4)
Rhine	2005	-0.17 (0.32, 19) / -1.65 (0.4, 18)	0.3 (0.33, 132) / -0.79 (0.1, 17)
Rhone	2005	n.a. / n.a.	0.02 (0.39, 92) / -0.44 (1.05, 73)
Scheldt	2005	-0.26 (0.56, 4) / -0.75 (0.14, 4)	0.66 (0.17, 39) / n.a.
Schlei	2005	-0.84 (0.35, 2) / -1.26 (0.03, 2)	0.26 (0.39, 2) / n.a.
Scotland	2005	-0.74 (0.45, 8) / -1.82 (0.62, 8)	-0.57 (0.4, 12) / n.a.
Segura	2005	n.a. / n.a.	-0.35 (0.53, 7) / n.a.
Seine	2005	n.a. / -1.47 (0.12, 3)	0.65 (0.18, 51) / -1.21 (0.5, 88)
Serchio	2005	n.a. / n.a.	-0.27 (0.3, 10) / n.a.
Severn	2005	n.a. / n.a.	0.56 (0.43, 15) / n.a.
Sicily	2005	-0.23 (0.93, 16) / n.a.	n.a. / n.a.
Solway	2005	n.a. / n.a.	0.17 (0.53, 4) / n.a.
South Appenines	2005	-0.48 (0.58, 6) / n.a.	0.24 (0.5, 54) / n.a.
South East (Irl.)	2005	n.a. / n.a.	0.56 (0.2, 12) / n.a.
South East (UK)	2005	n.a. / n.a.	0.78 (0.15, 5) / n.a.
South West (UK)	2005	n.a. / n.a.	0.58 (0.27, 24) / n.a.
Tagus	2005	n.a. / n.a.	0.06 (0.5, 101) / n.a.
Thames	2005	n.a. / n.a.	0.66 (0.27, 13) / n.a.
Venta	2005	-1.01 (0.48, 7) / -1.57 (0.18, 7)	-0.03 (0.21, 21) / n.a.
Vistula	2005	n.a. / n.a.	0.09 (0.27, 69) / n.a.
Warnow	2005	n.a. / n.a.	0.35 (0.11, 4) / n.a.
Weser	2005	n.a. / n.a.	0.52 (0.11, 17) / n.a.
West Aegean	2005	n.a. / n.a.	-0.04 (0.27, 18) / n.a.
West Estonian	2005	n.a. / n.a.	0 (0.32, 18) / n.a.
Western	2005	n.a. / n.a.	-0.03 (0.26, 3) / n.a.
Western Wales	2005	n.a. / n.a.	0.22 (0.36, 12) / -1.25 (0.47, 7)
Adour	2006	n.a. / n.a.	0.23 (0.36, 178) / -0.71 (0.22, 3)
Algarve	2006	0.58 (0.17, 3) / -1.25 (0.21, 3)	-0.26 (0.27, 5) / -1.4 (0.17, 5)
Andalusia	2006	n.a. / n.a.	n.a. / -0.83 (0.33, 4)
Anglian	2006	n.a. / n.a.	0.86 (0.17, 17) / n.a.
Basque County	2006	n.a. / n.a.	-0.21 (0.18, 2) / -1.31 (0.45, 31)
Black Sea	2006	-0.35 (0.14, 2) / n.a.	-0.15 (0.51, 8) / -0.76 (0.15, 8)
Cantabrian	2006	n.a. / n.a.	-0.04 (0.23, 16) / n.a.
Catalan	2006	n.a. / n.a.	n.a. / -1.25 (0.55, 451)
Cavado	2006	0.3 (0, 3) / -1.47 (0.05, 3)	0.19 (0.2, 5) / -1.07 (0.49, 5)
Corsica	2006	n.a. / n.a.	-0.46 (0.12, 8) / -1.1 (0.23, 10)
Cyprus	2006	n.a. / n.a.	-0.08 (0.68, 5) / -1.32 (0.37, 56)
Danube	2006	-0.62 (0.52, 27) / -1.73 (0.53, 52)	0.11 (0.36, 611) / -1.29 (0.3, 33)
Daugava	2006	-0.55 (0.51, 6) / -1.23 (0.21, 6)	-0.24 (0.07, 10) / -1.5 (0.09, 2)
Douro	2006	0.55 (0.2, 3) / -1.2 (0.3, 3)	0 (0.46, 68) / -0.93 (0.21, 81)
East Aegean Islands	2006	-0.77 (0.67, 7) / -1.18 (0.55, 4)	-0.17 (0.5, 43) / -0.85 (0.08, 3)

Appendix S7.2

Basin	Year	Lake	Stream
East Alps	2006	-0.43 (0.28, 5) / n.a.	n.a. / n.a.
East Estonia	2006	-1.22 (0.47, 10) / -1.43 (0.38, 11)	-0.02 (0.37, 33) / -1.09 (0.2, 8)
East Sterea	2006	n.a. / n.a.	n.a. / -0.82 (0.6, 44)
Ebro	2006	n.a. / n.a.	0.19 (0.41, 92) / -0.67 (0.82, 9)
Elbe	2006	-0.17 (0.37, 8) / n.a.	0.42 (0.28, 81) / -1 (0.18, 31)
Ems	2006	n.a. / n.a.	0.6 (0.06, 3) / -1.21 (0.3, 178)
Galician	2006	n.a. / n.a.	n.a. / -1.19 (0.32, 216)
Gauja	2006	-0.74 (0.44, 3) / 1.04 (0.37, 7)	-0.16 (0.16, 8) / n.a.
Guadalquivir	2006	n.a. / n.a.	0.16 (0.42, 33) / -1.19 (0.37, 150)
Guadiana	2006	0.2 (0.14, 5) / -1.41 (0.29, 3)	-0.05 (0.39, 13) / -1.2 (0.47, 3)
Humber	2006	n.a. / -1.35 (0.34, 12)	0.7 (0.34, 38) / -0.87 (0.39, 18)
Jucar	2006	n.a. / n.a.	n.a. / -1.45 (0.12, 5)
Jutland	2006	-0.45 (0.72, 12) / n.a.	n.a. / n.a.
Lielupe	2006	n.a. / n.a.	0.25 (0.26, 18) / -1.01 (0.51, 127)
Loire	2006	n.a. / n.a.	0.53 (0.36, 216) / -1.58 (0.21, 6)
Meuse	2006	n.a. / n.a.	0.49 (0.19, 49) / -1.28 (0.22, 3)
Middle Appenines	2006	-0.54 (0.56, 11) / n.a.	-0.18 (0.13, 5) / n.a.
Minho	2006	n.a. / n.a.	-0.11 (0.23, 17) / -0.55 (0.4, 73)
Minho Lima	2006	n.a. / n.a.	0.05 (0.2, 5) / -1.1 (0.29, 5)
Mosel	2006	n.a. / n.a.	0.68 (0.23, 3) / -0.86 (0.03, 2)
Neagh Bann	2006	n.a. / n.a.	n.a. / -1.59 (0.53, 84)
Nemunas	2006	-0.94 (0.67, 12) / -1.36 (0.41, 12)	-0.04 (0.25, 38) / -0.98 (0.39, 4)
North Adriatic	2006	n.a. / n.a.	-0.06 (0.2, 6) / -1.55 (0.2, 11)
North Appenines	2006	-0.08 (0.61, 8) / n.a.	-0.02 (0.34, 69) / -0.8 (0.67, 79)
North East (UK)	2006	n.a. / n.a.	n.a. / -0.92 (0.61, 3)
North West (UK)	2006	n.a. / -1.45 (0.25, 13)	0.38 (0.4, 23) / n.a.
Northumbria	2006	n.a. / n.a.	-0.1 (0.45, 12) / -1.03 (0.59, 7)
Oder	2006	n.a. / n.a.	0.32 (0.25, 75) / -0.79 (0.34, 70)
Po	2006	-0.34 (0.51, 31) / -1.38 (0.41, 31)	n.a. / n.a.
Pregolya	2006	n.a. / n.a.	0.2 (0.18, 4) / -0.86 (0.05, 4)
Rhine	2006	-0.17 (0.57, 18) / -1.46 (0.86, 17)	0.33 (0.31, 142) / -0.77 (0.14, 17)
Rhone	2006	n.a. / n.a.	0.13 (0.34, 140) / -0.72 (0.32, 75)
Sado	2006	0.16 (0.2, 4) / -1.09 (0.1, 4)	n.a. / n.a.
Scheldt	2006	-0.4 (0.53, 4) / -0.82 (0.26, 4)	0.65 (0.2, 73) / n.a.
Schlei	2006	1.61 (0.01, 2) / 1.05 (0.01, 2)	0.34 (0.38, 2) / n.a.
Scotland	2006	n.a. / n.a.	-0.31 (0.7, 199) / n.a.
Seine	2006	n.a. / -1.68 (0.98, 12)	0.69 (0.19, 150) / -1.27 (0.48, 57)
Serchio	2006	n.a. / n.a.	-0.25 (0.28, 11) / n.a.
Severn	2006	n.a. / n.a.	0.57 (0.42, 15) / n.a.
Sicily	2006	-0.33 (0.2, 4) / n.a.	n.a. / n.a.
Solway	2006	n.a. / n.a.	0.02 (0.51, 39) / n.a.
South Appenines	2006	-0.03 (0.91, 5) / n.a.	n.a. / n.a.
South East (UK)	2006	n.a. / n.a.	0.79 (0.19, 5) / n.a.
South West (UK)	2006	n.a. / n.a.	0.59 (0.27, 24) / n.a.

Basin	Year	Lake	Stream
Tagus	2006	n.a. / n.a.	0.13 (0.49, 81) / n.a.
Tagus West	2006	0.34 (0.21, 7) / -0.95 (0.43, 5)	0.12 (0.35, 15) / -0.6 (0.43, 12)
Thames	2006	n.a. / n.a.	0.72 (0.23, 13) / n.a.
Venta	2006	-0.85 (0.58, 6) / -1.32 (0.34, 6)	0.08 (0.21, 19) / n.a.
Vistula	2006	n.a. / n.a.	0.08 (0.25, 69) / n.a.
Vouga	2006	n.a. / n.a.	0.07 (0.4, 10) / -1.37 (0.06, 2)
Warnow	2006	n.a. / n.a.	0.22 (0.04, 4) / n.a.
Weser	2006	n.a. / n.a.	0.57 (0.12, 17) / n.a.
West Aegean	2006	n.a. / n.a.	-0.06 (0.25, 15) / n.a.
West Estonian	2006	n.a. / n.a.	-0.01 (0.26, 18) / n.a.
Western Wales	2006	n.a. / n.a.	0.23 (0.37, 13) / n.a.
Adour	2007	n.a. / n.a.	0.24 (0.35, 178) / -0.56 (0.45, 4)
Aegean Islands	2007	n.a. / n.a.	0.15 (0.38, 2) / 0.01 (0.26, 2)
Algarve	2007	0.32 (0.1, 3) / -1.63 (0.2, 3)	-0.26 (0.28, 4) / -1.37 (0.15, 3)
Anglian	2007	n.a. / n.a.	0.92 (0.11, 17) / -1.11 (0.59, 4)
Basque County	2007	n.a. / n.a.	0.13 (0.18, 18) / -1.01 (0.52, 18)
Black Sea	2007	-0.2 (0.21, 4) / -1.9 (0, 3)	-0.25 (0.36, 8) / -0.99 (0.11, 4)
Cantabrian	2007	n.a. / n.a.	-0.35 (0.7, 18) / -1.38 (0.43, 22)
Catalan	2007	n.a. / n.a.	n.a. / -0.67 (0.92, 244)
Cavado	2007	0 (0, 2) / n.a.	0.31 (0.28, 7) / n.a.
Central Macedonia	2007	n.a. / n.a.	0.7 (0.18, 8) / -0.33 (0.47, 8)
Corsica	2007	n.a. / n.a.	-0.39 (0.2, 22) / -1.18 (0.17, 19)
Cyprus	2007	n.a. / n.a.	0.02 (0.48, 21) / -0.57 (0.49, 45)
Danube	2007	-0.23 (0.45, 39) / -1.56 (0.8, 38)	0.1 (0.38, 306) / -1.42 (0.25, 37)
Daugava	2007	-0.95 (0.46, 7) / -1.58 (0.27, 7)	-0.17 (0.21, 19) / -1.47 (0.43, 231)
Douro	2007	0.61 (0.32, 5) / n.a.	-0.08 (0.64, 71) / -1.01 (0.26, 39)
East	2007	n.a. / n.a.	-0.05 (0.17, 2) / n.a.
East Aegean Islands	2007	-0.72 (0.49, 7) / -1.26 (0.99, 2)	-0.2 (0.49, 45) / n.a.
East Alps	2007	-0.51 (0.43, 13) / n.a.	0.01 (0.32, 65) / -0.8 (0.45, 14)
East Estonia	2007	-0.88 (0.46, 10) / -1.39 (0.22, 14)	0.11 (0.39, 37) / -1.04 (0.14, 7)
East Sterea	2007	n.a. / n.a.	0.67 (0.14, 12) / -0.88 (0.75, 67)
Ebro	2007	n.a. / n.a.	0.01 (0.57, 232) / -1.25 (0.38, 3)
Elbe	2007	n.a. / n.a.	0.38 (0.25, 39) / -1.01 (0.13, 31)
Ems	2007	n.a. / n.a.	n.a. / -1.14 (0.33, 178)
Epirus	2007	n.a. / n.a.	0.41 (0.28, 14) / n.a.
Galician	2007	n.a. / n.a.	-0.01 (0.2, 26) / -1.09 (0.28, 419)
Gauja	2007	-0.33 (0.32, 6) / n.a.	-0.06 (0.23, 7) / n.a.
Guadalquivir	2007	n.a. / n.a.	0.15 (0.65, 68) / -1.2 (0.38, 217)
Guadiana	2007	0.31 (0.13, 5) / -1.18 (0.46, 6)	-0.24 (0.59, 14) / -1.43 (0.49, 382)
Humber	2007	n.a. / -1.34 (0.3, 5)	0.75 (0.32, 37) / -1.09 (0.26, 26)
Jucar	2007	n.a. / n.a.	0.29 (0.51, 62) / -0.96 (0.59, 264)
Lielupe	2007	-0.14 (0.48, 4) / n.a.	0.74 (0.28, 26) / -0.96 (0.41, 110)
Loire	2007	n.a. / n.a.	0.5 (0.38, 419) / -2.12 (0.52, 7)
Meuse	2007	n.a. / n.a.	0.45 (0.18, 52) / -1.15 (0.36, 4)

Appendix S7.2

Basin	Year	Lake	Stream
Middle Appenines	2007	-0.58 (0.75, 24) / n.a.	0.02 (0.44, 256) / n.a.
Minho	2007	n.a. / n.a.	-0.1 (0.28, 16) / -0.48 (0.38, 77)
Minho Lima	2007	n.a. / n.a.	0.08 (0.22, 5) / n.a.
Mosel	2007	n.a. / n.a.	0.6 (0.18, 4) / n.a.
Neagh Bann	2007	n.a. / n.a.	n.a. / -1.56 (0.48, 201)
Nemunas	2007	-0.9 (0.4, 14) / -1.67 (0.24, 14)	0.04 (0.44, 38) / -0.77 (0.26, 2)
North Adriatic	2007	n.a. / n.a.	-0.14 (0.21, 7) / -1.41 (0.29, 44)
North Appenines	2007	-0.42 (0.43, 15) / n.a.	0.05 (0.36, 169) / -0.78 (0.52, 81)
North East (UK)	2007	n.a. / n.a.	n.a. / -0.96 (0.64, 2)
North Peloponese	2007	n.a. / n.a.	0.45 (0.39, 9) / n.a.
North West (Irl.)	2007	n.a. / n.a.	-0.25 (0.28, 5) / -1.09 (0.69, 62)
North West (UK)	2007	n.a. / -1.6 (0.3, 16)	0.43 (0.37, 18) / n.a.
Northumbria	2007	n.a. / n.a.	-0.01 (0.48, 6) / -0.9 (0.64, 6)
Oder	2007	n.a. / n.a.	0.35 (0.26, 63) / -0.82 (0.34, 68)
Po	2007	-0.41 (0.42, 40) / -1.64 (0.49, 100)	-0.06 (0.45, 88) / n.a.
Pregolya	2007	n.a. / n.a.	0.27 (0.14, 4) / n.a.
Rhine	2007	-0.06 (0.3, 16) / -1.64 (0.46, 16)	0.26 (0.31, 110) / -0.35 (0.36, 16)
Rhone	2007	n.a. / n.a.	-0.02 (0.43, 382) / -0.8 (0.3, 63)
Sado	2007	0.21 (0.19, 4) / -1.2 (0.24, 4)	n.a. / n.a.
Scheldt	2007	-0.14 (0.33, 4) / -0.98 (0.11, 4)	0.66 (0.18, 77) / -0.7 (0.37, 7)
Scotland	2007	n.a. / n.a.	-0.36 (0.71, 205) / n.a.
Segura	2007	n.a. / n.a.	0.06 (0.03, 2) / n.a.
Seine	2007	n.a. / -1.17 (0.28, 4)	0.68 (0.21, 217) / -1.19 (0.7, 210)
Serchio	2007	n.a. / n.a.	-0.24 (0.32, 16) / n.a.
Severn	2007	n.a. / n.a.	0.54 (0.49, 14) / n.a.
Shannon	2007	n.a. / n.a.	-0.11 (0.82, 14) / n.a.
Sicily	2007	n.a. / n.a.	0.5 (0.35, 31) / -1.09 (0.65, 32)
Solway	2007	n.a. / n.a.	-0.06 (0.59, 44) / n.a.
South Appenines	2007	-0.43 (0.53, 16) / n.a.	0.08 (0.44, 206) / n.a.
South East (Irl.)	2007	n.a. / n.a.	0.51 (0.18, 30) / n.a.
South East (UK)	2007	n.a. / n.a.	0.69 (0.18, 5) / n.a.
South West (Irl.)	2007	n.a. / -1.59 (0.39, 5)	0.33 (0.39, 18) / -1.93 (0.16, 2)
South West (UK)	2007	n.a. / n.a.	0.58 (0.29, 18) / n.a.
Tagus	2007	n.a. / n.a.	0.05 (0.57, 83) / n.a.
Tagus West	2007	0.41 (0.29, 8) / n.a.	0.14 (0.3, 15) / n.a.
Thames	2007	n.a. / n.a.	0.71 (0.2, 13) / n.a.
Thrace	2007	n.a. / n.a.	0.67 (0.25, 15) / n.a.
Venta	2007	-0.65 (0.51, 8) / -1.33 (0.36, 8)	0.09 (0.23, 14) / n.a.
Vistula	2007	n.a. / n.a.	0.12 (0.26, 68) / n.a.
Vouga	2007	n.a. / n.a.	0.14 (0.25, 11) / n.a.
West Aegean	2007	n.a. / n.a.	-0.13 (0.33, 16) / n.a.
West Estonian	2007	n.a. / n.a.	0.28 (0.31, 22) / n.a.
West Macedonia	2007	n.a. / n.a.	0.5 (0.4, 7) / n.a.
West Sterea	2007	n.a. / n.a.	-0.08 (0.55, 6) / -0.96 (0.14, 2)

Basin	Year	Lake	Stream
Western	2007	n.a. / n.a.	n.a. / -1.51 (0.22, 5)
Western Wales	2007	n.a. / n.a.	0.18 (0.43, 13) / n.a.
Adour	2008	n.a. / n.a.	0.23 (0.42, 312) / -0.63 (0.35, 4)
Aegean Islands	2008	n.a. / n.a.	n.a. / 0.89 (1.75, 2)
Algarve	2008	-0.5 (0.1, 3) / -1.65 (0.17, 3)	-0.51 (0.34, 5) / -1.72 (0.25, 5)
Andalusia	2008	n.a. / n.a.	0.11 (0.53, 25) / -1.08 (0.82, 25)
Anglian	2008	n.a. / n.a.	0.86 (0.12, 15) / -1.96 (0.49, 4)
Basque County	2008	n.a. / n.a.	0.02 (0.26, 37) / -1.4 (0.47, 39)
Black Sea	2008	-0.11 (0.3, 4) / -1.3 (0, 3)	-0.18 (0.5, 5) / 1.45 (1.27, 7)
Cantabrian	2008	n.a. / n.a.	-0.31 (0.43, 24) / -1.39 (0.63, 18)
Catalan	2008	n.a. / n.a.	0.15 (0.5, 175) / -1.07 (0.46, 320)
Cavado	2008	n.a. / n.a.	0.3 (0.31, 7) / n.a.
Corsica	2008	n.a. / n.a.	-0.45 (0.18, 22) / -1.15 (0.2, 15)
Cyprus	2008	n.a. / n.a.	-0.25 (0.57, 18) / n.a.
Danube	2008	-0.42 (0.33, 43) / -1.87 (0.54, 40)	0.1 (0.32, 360) / -1.25 (0.34, 69)
Daugava	2008	-0.82 (0.48, 3) / -1.42 (0.3, 3)	-0.18 (0.19, 15) / -1.8 (0.59, 264)
Douro	2008	-0.28 (0.44, 5) / -1.78 (0.38, 6)	-0.12 (0.65, 82) / -0.94 (0.25, 80)
East Aegean Islands	2008	-0.46 (0.36, 7) / -0.44 (0.05, 3)	-0.15 (0.39, 41) / -0.68 (0.17, 9)
East Alps	2008	-0.6 (0.37, 15) / n.a.	0.03 (0.28, 66) / 0.1 (1.42, 14)
East Estonia	2008	-0.95 (0.49, 8) / -1.44 (0.25, 14)	0.16 (0.4, 37) / -1.14 (0.13, 7)
East Sterea	2008	n.a. / n.a.	n.a. / -0.93 (0.77, 114)
Ebro	2008	n.a. / n.a.	-0.04 (0.56, 264) / -1.49 (0.61, 3)
Eider	2008	n.a. / n.a.	0.39 (0.05, 2) / n.a.
Elbe	2008	-0.31 (0.68, 18) / -1.94 (0.3, 7)	0.4 (0.29, 91) / -0.99 (0.12, 30)
Ems	2008	n.a. / n.a.	0.46 (0.19, 9) / -1.32 (0.34, 312)
Galician	2008	n.a. / n.a.	-0.06 (0.25, 37) / -1.11 (0.27, 419)
Gauja	2008	-0.41 (0.47, 3) / -1.26 (0.43, 18)	-0.08 (0.18, 7) / n.a.
Guadalete	2008	n.a. / n.a.	0.32 (0.47, 19) / -0.82 (0.51, 19)
Guadalquivir	2008	n.a. / n.a.	0.13 (0.68, 127) / -1.22 (0.36, 217)
Guadiana	2008	-0.36 (0.14, 5) / -1.32 (0.27, 3)	-0.44 (0.47, 6) / -1.46 (0.46, 392)
Humber	2008	n.a. / -1.23 (0.39, 5)	0.67 (0.33, 33) / -1.04 (0.33, 18)
Jucar	2008	n.a. / n.a.	0.22 (0.6, 89) / -0.98 (0.59, 159)
Lielupe	2008	n.a. / n.a.	0.41 (0.5, 18) / n.a.
Loire	2008	n.a. / n.a.	0.5 (0.36, 419) / -1.65 (0.31, 7)
Meuse	2008	0.34 (0.26, 2) / -1.44 (0.49, 2)	0.45 (0.19, 57) / -0.94 (0.38, 175)
Middle Appenines	2008	-0.58 (0.55, 16) / n.a.	0.13 (0.35, 89) / n.a.
Minho	2008	n.a. / n.a.	n.a. / -0.49 (0.38, 80)
Minho Lima	2008	n.a. / n.a.	0.01 (0.38, 4) / n.a.
Mosel	2008	n.a. / n.a.	0.64 (0.18, 4) / n.a.
Neagh Bann	2008	n.a. / n.a.	n.a. / -1.5 (0.46, 197)
Nemunas	2008	-0.9 (0.39, 9) / -1.66 (0.28, 9)	-0.04 (0.22, 37) / -1.3 (0.21, 17)
North Adriatic	2008	n.a. / n.a.	-0.17 (0.3, 7) / -1.42 (0.27, 46)
North Appenines	2008	-0.47 (0.61, 17) / n.a.	0.01 (0.4, 219) / -0.95 (0.7, 237)
North East (UK)	2008	n.a. / n.a.	n.a. / -0.88 (0.52, 2)

Appendix S7.2

Basin	Year	Lake	Stream
North West (Irl.)	2008	n.a. / n.a.	n.a. / -1.18 (0.76, 89)
North West (UK)	2008	n.a. / -1.79 (0.23, 17)	0.38 (0.4, 17) / n.a.
Northumbria	2008	n.a. / n.a.	-0.02 (0.48, 6) / -0.95 (0.61, 6)
Oder	2008	n.a. / n.a.	0.3 (0.25, 65) / -0.89 (0.38, 62)
Po	2008	-0.56 (0.5, 100) / -1.87 (0.85, 100)	0.04 (0.35, 302) / n.a.
Pregolya	2008	n.a. / n.a.	0.2 (0.13, 4) / n.a.
Rhine	2008	-0.11 (0.29, 15) / -1.77 (0.38, 14)	0.37 (0.29, 182) / -0.84 (0.13, 39)
Rhone	2008	n.a. / n.a.	-0.04 (0.42, 392) / -0.77 (0.31, 67)
Sado	2008	-0.6 (0.1, 4) / -1.29 (0.1, 4)	n.a. / n.a.
Scheldt	2008	-0.22 (0.4, 3) / -0.95 (0.18, 3)	0.67 (0.18, 80) / 1.12 (0.29, 6)
Schlei	2008	-0.78 (0.15, 4) / -1.64 (0.14, 3)	0.53 (0.22, 9) / n.a.
Scotland	2008	n.a. / n.a.	-0.4 (0.72, 205) / n.a.
Segura	2008	n.a. / n.a.	-0.1 (0.38, 8) / -0.9 (0.66, 6)
Seine	2008	n.a. / -1.51 (0.33, 24)	0.65 (0.22, 217) / -1.21 (0.56, 214)
Serchio	2008	n.a. / n.a.	-0.36 (0.22, 17) / n.a.
Severn	2008	n.a. / n.a.	0.47 (0.48, 13) / n.a.
Solway	2008	n.a. / n.a.	-0.05 (0.54, 46) / n.a.
South Appenines	2008	0.07 (0.62, 6) / n.a.	0.35 (0.57, 17) / n.a.
South East (UK)	2008	n.a. / n.a.	0.66 (0.2, 5) / n.a.
South West (UK)	2008	n.a. / n.a.	0.58 (0.29, 18) / n.a.
Tagus	2008	n.a. / n.a.	-0.2 (0.63, 253) / n.a.
Tagus West	2008	-0.44 (0.36, 7) / n.a.	-0.19 (0.36, 10) / n.a.
Thames	2008	n.a. / n.a.	0.69 (0.19, 10) / n.a.
Venta	2008	-0.97 (0.2, 3) / -1.17 (0.42, 3)	-0.05 (0.23, 17) / n.a.
Vistula	2008	n.a. / n.a.	0.1 (0.28, 56) / n.a.
Vouga	2008	n.a. / n.a.	0.05 (0.32, 11) / n.a.
Warnow	2008	n.a. / n.a.	0.24 (0.24, 7) / n.a.
Weser	2008	n.a. / n.a.	0.55 (0.16, 44) / n.a.
West Aegean	2008	n.a. / n.a.	-0.15 (0.39, 14) / n.a.
West Estonian	2008	n.a. / n.a.	0.27 (0.31, 22) / n.a.
Western Wales	2008	n.a. / n.a.	0.15 (0.4, 13) / n.a.
Adour	2009	n.a. / n.a.	0.26 (0.42, 231) / -1.38 (0.21, 3)
Algarve	2009	-0.8 (0.14, 3) / -1.7 (0.13, 3)	-0.54 (0.39, 5) / -1.72 (0.19, 4)
Andalusia	2009	n.a. / n.a.	0.3 (0.41, 25) / -0.95 (0.74, 23)
Anglian	2009	n.a. / n.a.	0.82 (0.12, 13) / -1.6 (0.76, 4)
Basque County	2009	n.a. / n.a.	-0.02 (0.33, 42) / -0.18 (0.03, 2)
Black Sea	2009	-0.57 (0.05, 2) / n.a.	-0.18 (0.42, 5) / -1.28 (0.46, 4)
Cantabrian	2009	n.a. / n.a.	-0.51 (0.45, 32) / -1.76 (0.57, 23)
Catalan	2009	n.a. / n.a.	0.29 (0.52, 231) / n.a.
Cavado	2009	-0.61 (0.05, 2) / n.a.	0.19 (0.21, 5) / -1.07 (0.44, 286)
Corsica	2009	n.a. / n.a.	-0.46 (0.14, 22) / -1.19 (0.1, 12)
Cyprus	2009	n.a. / n.a.	-0.68 (0.93, 23) / -0.73 (0.28, 19)
Danube	2009	-0.33 (0.33, 38) / -1.74 (0.62, 35)	0.09 (0.34, 297) / -1.31 (0.38, 33)
Daugava	2009	-0.81 (0.69, 10) / -1.38 (0.26, 10)	-0.02 (0.22, 12) / -1.87 (0.53, 262)

Basin	Year	Lake	Stream
Douro	2009	-0.22 (0.36, 7) / -1.93 (0.32, 6)	-0.04 (0.52, 82) / n.a.
East	2009	n.a. / n.a.	n.a. / -0.84 (0.18, 43)
East Aegean Islands	2009	-0.59 (0.4, 7) / -1.1 (0.11, 5)	-0.21 (0.42, 34) / -0.71 (0.17, 9)
East Alps	2009	-0.48 (0.29, 10) / -1.97 (0.29, 10)	0.22 (0.26, 33) / -1.26 (0.46, 37)
East Estonia	2009	n.a. / n.a.	0.07 (0.39, 37) / -1.13 (0.14, 6)
Ebro	2009	n.a. / n.a.	-0.07 (0.62, 263) / -0.91 (0.65, 103)
Eider	2009	n.a. / n.a.	0.29 (0.1, 2) / -0.73 (0.1, 2)
Elbe	2009	-0.4 (0.67, 20) / n.a.	0.33 (0.37, 43) / -1.02 (0.12, 30)
Ems	2009	n.a. / n.a.	0.44 (0.22, 9) / -1.27 (0.36, 226)
Galician	2009	n.a. / n.a.	-0.05 (0.26, 37) / n.a.
Gauja	2009	-0.56 (0.47, 3) / -1.11 (0.34, 24)	-0.05 (0.18, 6) / -1.09 (0.29, 415)
Guadalete	2009	n.a. / n.a.	0.53 (0.45, 21) / n.a.
Guadalquivir	2009	n.a. / n.a.	0.29 (0.65, 130) / -1.22 (0.35, 216)
Guadiana	2009	-0.59 (0.23, 5) / -1.29 (0.29, 3)	-0.56 (0.48, 4) / -1.51 (0.44, 301)
Humber	2009	n.a. / -1.06 (0.66, 5)	0.64 (0.37, 26) / -1.13 (0.37, 15)
Jucar	2009	n.a. / n.a.	0.27 (0.47, 80) / -1.04 (0.4, 55)
Jutland	2009	n.a. / -1.21 (0.53, 10)	n.a. / n.a.
Lielupe	2009	n.a. / n.a.	0.26 (0.5, 15) / n.a.
Loire	2009	-0.65 (0.25, 10) / n.a.	0.45 (0.36, 419) / -1.13 (0.22, 38)
Meuse	2009	n.a. / n.a.	0.44 (0.19, 55) / -0.94 (0.36, 182)
Middle Appenines	2009	n.a. / n.a.	-0.24 (0.26, 5) / n.a.
Minho	2009	n.a. / n.a.	n.a. / -0.5 (0.41, 81)
Minho Lima	2009	n.a. / n.a.	0.08 (0.29, 4) / n.a.
Mosel	2009	n.a. / n.a.	0.66 (0.11, 3) / -0.81 (0.07, 9)
Neagh Bann	2009	-0.56 (0.29, 12) / -1.11 (0.4, 13)	0.06 (0.25, 29) / -1.51 (0.43, 199)
Nemunas	2009	-0.91 (0.37, 11) / -1.69 (0.33, 11)	0 (0.28, 38) / -1.42 (0.16, 11)
North Adriatic	2009	n.a. / n.a.	-0.18 (0.22, 5) / -1.46 (0.26, 45)
North Appenines	2009	n.a. / -0.55 (0.45, 2)	0.03 (0.38, 57) / -0.89 (0.7, 173)
North East (UK)	2009	-0.62 (0.08, 3) / -1.4 (0.5, 3)	-0.08 (0.53, 19) / -0.67 (0.2, 3)
North West (Irl.)	2009	n.a. / n.a.	-0.71 (0.61, 2) / -1.32 (0.73, 70)
North West (UK)	2009	-0.66 (0.23, 16) / -1.82 (0.21, 17)	-0.17 (0.53, 55) / n.a.
Northumbria	2009	n.a. / n.a.	-0.14 (0.59, 6) / -1.08 (0.5, 12)
Oder	2009	-1.21 (0.01, 2) / n.a.	0.33 (0.23, 37) / -0.92 (0.33, 58)
Po	2009	-0.41 (0.31, 6) / -1.38 (0.48, 6)	0.41 (0.04, 4) / n.a.
Pregolya	2009	n.a. / n.a.	n.a. / -0.98 (0.17, 7)
Rhine	2009	-0.09 (0.41, 10) / -1.83 (0.46, 10)	0.36 (0.28, 182) / -0.81 (0.17, 44)
Rhone	2009	n.a. / n.a.	-0.09 (0.46, 315) / -0.78 (0.22, 53)
Sado	2009	-0.54 (0.13, 4) / -1.4 (0.09, 4)	n.a. / n.a.
Scheldt	2009	-0.63 (0.54, 6) / -0.68 (0.32, 6)	0.63 (0.2, 81) / -1.29 (0.23, 22)
Schlei	2009	-0.48 (0.12, 3) / -1.09 (0.23, 3)	0.46 (0.2, 9) / n.a.
Scotland	2009	n.a. / n.a.	-0.43 (0.74, 207) / n.a.
Segura	2009	n.a. / n.a.	-0.29 (0.17, 6) / n.a.
Seine	2009	n.a. / -1.77 (0.24, 11)	0.64 (0.21, 217) / -1.28 (0.48, 61)
Serchio	2009	n.a. / n.a.	-0.44 (0.32, 11) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
Severn	2009	n.a. / n.a.	0.4 (0.48, 11) / n.a.
Solway	2009	n.a. / n.a.	-0.15 (0.55, 45) / n.a.
South East (UK)	2009	n.a. / n.a.	0.69 (0.21, 4) / n.a.
South West (Irl.)	2009	n.a. / -1.91 (0.41, 16)	n.a. / n.a.
South West (UK)	2009	n.a. / n.a.	0.53 (0.3, 16) / n.a.
Tagus	2009	n.a. / -0.86 (0.46, 2)	-0.08 (0.63, 213) / n.a.
Tagus West	2009	-0.42 (0.26, 6) / n.a.	-0.59 (0.57, 6) / n.a.
Thames	2009	n.a. / n.a.	0.67 (0.26, 9) / n.a.
Venta	2009	-1.16 (0.69, 5) / -1.53 (0.16, 5)	-0.03 (0.22, 16) / n.a.
Vistula	2009	n.a. / n.a.	0.14 (0.25, 59) / n.a.
Vouga	2009	n.a. / n.a.	0.02 (0.37, 12) / n.a.
Warnow	2009	-1.26 (0.44, 3) / -1.11 (0.38, 3)	0 (0.18, 7) / n.a.
Weser	2009	-0.22 (0.82, 2) / -1.16 (0.2, 2)	0.5 (0.16, 44) / n.a.
West Aegean	2009	n.a. / n.a.	-0.1 (0.24, 9) / n.a.
West Estonian	2009	n.a. / n.a.	0.06 (0.37, 22) / n.a.
Western Wales	2009	n.a. / n.a.	0.12 (0.41, 12) / n.a.
Adour	2010	-0.43 (0.39, 17) / -1.58 (0.55, 17)	0.2 (0.41, 357) / -1.8 (0.14, 2)
Algarve	2010	-0.59 (0.12, 3) / -1.43 (0.04, 3)	-0.49 (0.29, 5) / -1.51 (0.16, 5)
Andalusia	2010	n.a. / n.a.	0.22 (0.47, 30) / -1.13 (0.6, 30)
Anglian	2010	n.a. / n.a.	0.85 (0.17, 86) / -0.9 (0.29, 23)
Basque County	2010	n.a. / n.a.	0.06 (0.21, 39) / -0.05 (0.14, 2)
Black Sea	2010	-0.28 (0.84, 3) / -1.9 (0, 3)	-0.23 (0.53, 8) / -1.25 (0.78, 5)
Cantabrian	2010	n.a. / n.a.	-0.5 (0.47, 205) / -1.89 (0.18, 22)
Catalan	2010	n.a. / n.a.	0.25 (0.52, 274) / n.a.
Cavado	2010	n.a. / n.a.	n.a. / -1.12 (0.43, 276)
Corsica	2010	n.a. / n.a.	-0.58 (0.2, 22) / -1.22 (0.18, 3)
Cyprus	2010	n.a. / n.a.	0.02 (0.71, 28) / -0.82 (0.59, 19)
Danube	2010	-0.38 (0.27, 39) / -1.8 (0.51, 38)	0.1 (0.33, 290) / -1.3 (0.41, 362)
Daugava	2010	n.a. / -1.88 (0.45, 4)	-0.16 (0.05, 3) / -1.49 (0.49, 188)
Douro	2010	n.a. / -1.99 (0.31, 6)	-0.05 (0.46, 66) / n.a.
East	2010	-0.76 (0.31, 4) / n.a.	0.06 (0.33, 3) / -1.52 (0.3, 3)
East Aegean Islands	2010	-0.58 (0.33, 7) / -1.28 (0.14, 5)	-0.02 (0.31, 37) / -0.71 (0.19, 9)
East Alps	2010	-0.41 (0.24, 15) / -1.83 (0.24, 15)	0.18 (0.36, 360) / -1.43 (0.49, 27)
East Estonia	2010	n.a. / n.a.	0.02 (0.39, 40) / -1.03 (0.55, 23)
Ebro	2010	n.a. / n.a.	-0.05 (0.62, 204) / -0.92 (0.75, 66)
Eider	2010	n.a. / n.a.	0.32 (0.06, 2) / n.a.
Elbe	2010	-0.37 (0.71, 17) / -1.96 (0.53, 17)	0.45 (0.33, 52) / -0.98 (0.17, 30)
Ems	2010	n.a. / n.a.	0.5 (0.25, 9) / -1.35 (0.38, 357)
Galician	2010	n.a. / n.a.	0.07 (0.18, 27) / n.a.
Gauja	2010	n.a. / -1.33 (0.4, 10)	n.a. / -1.14 (0.29, 419)
Guadalete	2010	n.a. / n.a.	0.5 (0.51, 22) / n.a.
Guadalquivir	2010	n.a. / n.a.	0.24 (0.54, 122) / -1.18 (0.3, 217)
Guadiana	2010	-0.51 (0.08, 5) / n.a.	-0.12 (0.49, 9) / -1.45 (0.44, 391)
Humber	2010	n.a. / -1.19 (0.34, 5)	0.53 (0.41, 109) / -1.24 (0.38, 10)

Basin	Year	Lake	Stream
Jucar	2010	n.a. / n.a.	0.27 (0.44, 82) / -1.05 (0.38, 55)
Jutland	2010	n.a. / -1.35 (0.22, 10)	n.a. / n.a.
Lielupe	2010	n.a. / n.a.	0.25 (0.64, 10) / n.a.
Loire	2010	0.41 (0.33, 7) / n.a.	0.5 (0.35, 419) / -1.11 (0.18, 35)
Meuse	2010	0.37 (0.13, 2) / n.a.	0.43 (0.2, 55) / -0.96 (0.32, 182)
Middle Appenines	2010	n.a. / n.a.	-0.19 (0.6, 38) / n.a.
Minho	2010	n.a. / n.a.	-0.18 (0.61, 41) / -0.6 (0.44, 80)
Mosel	2010	n.a. / n.a.	0.78 (0.18, 4) / -0.83 (0.07, 9)
Neagh Bann	2010	-0.56 (0.27, 8) / n.a.	0.07 (0.26, 28) / -1.49 (0.46, 199)
Nemunas	2010	-1.36 (0.16, 4) / -1.9 (0.28, 4)	0.03 (0.33, 35) / -1.6 (0.03, 8)
North Adriatic	2010	n.a. / n.a.	-0.23 (0.23, 5) / -1.45 (0.24, 53)
North Appenines	2010	n.a. / n.a.	-0.11 (0.52, 171) / -1.02 (0.64, 258)
North East (UK)	2010	-0.63 (0.18, 3) / n.a.	-0.08 (0.53, 19) / -0.51 (0.54, 7)
North West (Irl.)	2010	n.a. / n.a.	-0.57 (0.34, 7) / -1.62 (0.22, 2)
North West (UK)	2010	-0.63 (0.2, 15) / -1.92 (0.2, 17)	0.06 (0.54, 118) / n.a.
Northumbria	2010	n.a. / n.a.	-0.05 (0.49, 55) / -0.98 (0.63, 19)
Oder	2010	n.a. / n.a.	0.38 (0.23, 22) / -0.93 (0.21, 12)
Po	2010	-0.38 (0.45, 87) / 1 (1.07, 82)	-0.08 (0.39, 286) / n.a.
Pregolya	2010	n.a. / n.a.	n.a. / -0.98 (0.18, 7)
Rhine	2010	-0.09 (0.44, 12) / -1.86 (0.44, 12)	0.37 (0.29, 182) / -0.84 (0.17, 44)
Rhone	2010	n.a. / 1.19 (0.31, 13)	-0.03 (0.44, 391) / -0.77 (0.18, 21)
Sado	2010	-0.45 (0.11, 4) / -1.37 (0.21, 4)	n.a. / n.a.
Scheldt	2010	-0.5 (0.5, 6) / -0.91 (0.24, 6)	0.62 (0.19, 80) / -1.4 (0.24, 22)
Schlei	2010	-0.71 (0.61, 2) / n.a.	0.59 (0.18, 9) / n.a.
Scotland	2010	n.a. / n.a.	-0.41 (0.73, 207) / n.a.
Segura	2010	n.a. / n.a.	0.12 (0.63, 64) / n.a.
Seine	2010	n.a. / n.a.	0.67 (0.2, 217) / -1.37 (0.44, 170)
Serchio	2010	n.a. / n.a.	-0.45 (0.29, 25) / n.a.
Severn	2010	n.a. / n.a.	0.36 (0.38, 90) / n.a.
Shannon	2010	-0.94 (0.38, 10) / n.a.	-0.07 (0.42, 28) / n.a.
Solway	2010	n.a. / n.a.	0.01 (0.47, 76) / n.a.
South Appenines	2010	-0.01 (0.17, 4) / n.a.	-0.01 (0.47, 128) / n.a.
South East (Irl.)	2010	n.a. / n.a.	n.a. / -1.49 (0.08, 3)
South East (UK)	2010	n.a. / n.a.	0.61 (0.4, 52) / -0.87 (0.28, 7)
South West (Irl.)	2010	-1.2 (0.49, 2) / n.a.	0.06 (0.51, 23) / n.a.
South West (UK)	2010	n.a. / n.a.	0.44 (0.36, 134) / n.a.
Tagus	2010	n.a. / n.a.	-0.02 (0.59, 262) / n.a.
Tagus West	2010	-0.45 (0.16, 6) / n.a.	-0.46 (0.68, 9) / n.a.
Thames	2010	n.a. / n.a.	0.79 (0.21, 52) / n.a.
Venta	2010	n.a. / n.a.	0.09 (0.27, 9) / n.a.
Vistula	2010	-0.77 (0.39, 3) / -0.77 (0.2, 3)	0.06 (0.11, 13) / n.a.
Vouga	2010	n.a. / n.a.	-0.01 (0.36, 12) / n.a.
Warnow	2010	-0.41 (0.27, 3) / -1.19 (0.36, 4)	0.34 (0.28, 7) / n.a.
Weser	2010	-0.12 (0.67, 2) / -1.4 (0.42, 2)	0.55 (0.18, 44) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
West Aegean	2010	n.a. / n.a.	-0.14 (0.24, 10) / n.a.
West Estonian	2010	n.a. / n.a.	0.09 (0.32, 22) / n.a.
Western	2010	-1.24 (0.09, 2) / n.a.	n.a. / n.a.
Western Wales	2010	n.a. / n.a.	0.05 (0.36, 119) / n.a.

Appendix S7.3 River basins

River basins mapped by the European Environment Agency, EEA (2012) are shown in Figure S7.3.1 and the legend is shown in Table S7.3.1.

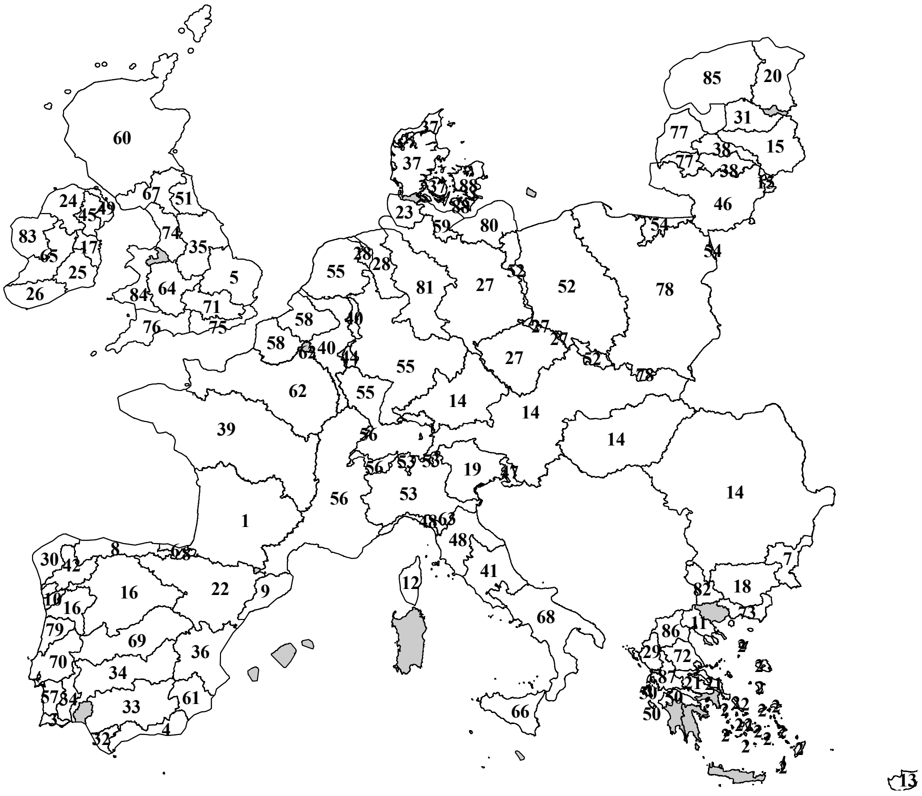

Figure S7.3.1. *River basins of temperate Europe.*

Appendix S7.3

Table S7.3.1 *Legend of river basin numbers used in Figures 7.3 and 7.4 of the main text.*

Number	Basin
1	Adour
2	Aegean Isl.
3	Algarve
4	Andalusia
5	Anglian
6	Basque County
7	Black Sea
8	Cantabrian
9	Catalan
10	Cavado
11	Central Macedonia
12	Corsica
13	Cyprus
14	Danube
15	Daugava
16	Douro
17	Eastern (IRL)
18	East Aegean Isl.
19	Eastern Alps
20	Eastern Estonia
21	Eastern Sterea
22	Ebro
23	Eider
24	North West (IRL)
25	South East (IRL)
26	South West (IRL)
27	Elbe
28	Ems
29	Epirus
30	Galician
31	Gauja
32	Guadalete
33	Guadalquivir
34	Guadiana
35	Humber
36	Jucar
37	Jutland
38	Lielupe
39	Loire
40	Meuse
41	Middle Appenines
42	Minho
43	Minho Lima
44	Mosel
45	Neagh Bann
46	Nemunas
47	North Adriatic
48	North Appenines
49	North East (UK)
50	North Peloponnese
51	Northumbria
52	Oder
53	Po
54	Pregolya
55	Rhine
56	Rhone
57	Sado
58	Scheldt
59	Schlei
60	Scotland
61	Segura
62	Seine
63	Serchio
64	Severn
65	Shannon
66	Sicily
67	Solway
68	Southern Appennines
69	Tagus
70	Tagus West
71	Thames
72	Thessalia

Number	Basin
73	Thrace
74	North West (UK)
75	South East (UK)
76	South West (UK)
77	Venta
78	Vistula
79	Vouga
80	Warnow
81	Weser
82	West Aegean
83	Western (IRL)
84	Western Wales
85	West Estonian
86	West Macedonia
87	West Sterea
88	Zealand

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SUMMARY

Increases in nutrient flows have led to increasing stressor levels in the environment. Ultimately, nutrient pollution may affect species growth, reproduction, and mortality, and, thereby, species occurrence as well as the richness of the community as a whole. In this thesis, nutrient pollution is assessed in three environmental compartments, i.e. marine waters, freshwaters, and on land. In each compartment, a different environmental problem was tackled: acidification of soils and of oceans and eutrophication of freshwaters. These are and, most likely, will remain, environmental issues at the global level.

In order to estimate the effects of nutrient pollution on species or species groups, stressor – response relationships were developed after a detailed data gathering, whereby species-specific effects and their respective stressor level were extracted from peer-reviewed literature. Long term biogeochemical processes, macroevolutionary patterns, and inherent species characteristics hold a vital role in the sensitivity of species to environmental stress and, accordingly, in determining the stressor – response relationships developed in the different chapters of this thesis. Finally, those relationships were applied for life cycle impact assessments (LCIA) and environmental risk assessments (ERA).

The issue of acidification is addressed in chapters 2 and 3 (for the terrestrial compartment) and in chapter 4 (in the marine compartment). In **chapter 2**, an inventory of the soil pH ranges at which different vascular plant species were reported in field surveys was conducted. Subsequently, the occurrence data were employed towards the derivation of relative species richness (RSR) as a function of soil pH in different biomes of the world. A total of 2409 species were inventoried and the individual species tolerance pH range was determined with the lowermost and uppermost pH levels at which the species was confirmed present. The logistic regressions were used to identify the sensitivity of biomes to decreases in RSR following soil pH declines. There, biogeographic patterns such as the discrepancy between pH conditions that maximize species richness in biomes and the difference in sensitivities across biomes could be identified. (Sub)tropical moist broadleaf forests are more sensitive to pH declines than other biomes while desert and xeric shrublands maintain their a high RSR at fairly high pH conditions.

In **chapter 3**, the cumulative increase in the potentially not occurring fraction (PNOF) of vascular species as a function of soil pH was derived from the lowermost surveyed pH level for each species in different terrestrial

biomes. The PNOF – pH relationships were then employed to derive quantitative relationships of the marginal increase in PNOF as a result of a marginal decline in soil pH (defined in LCIA as marginal effect factors) and, combined with existing models of atmospheric transport and soil chemistry, endpoint characterization factors (CFs) for terrestrial acidification were derived on a global scale for nitrogen oxides, ammonia, and sulfur dioxide emissions. The CFs express the environmental impact on the ecosystem per unit of acidifying pollutant emission (namely, the increase in the PNOF per unit of emission). CFs are provided at multiple levels of spatial resolution (highest resolution at 2.0º x 2.5º). The variability across CFs (of the magnitude of six orders) is determined mainly by the variability in soil sensitivity to atmospheric depositions.

In **chapter 4**, the cumulative increase in the potentially affected fraction (PAF) of marine calcifying species (e.g., arthropods, cnidarians, among others) as a function of water pH was estimated with species sensitivity distributions (SSDs). There, the PAF – pH relationships were developed from experimental data conveying subtle (EC_{10}) and severe (EC_{50}) effects on species growth, reproduction, and mortality. Subsequently, the PAF – pH functions were applied in an ERA by estimating the change in PAF expected with seawater pH declines in two global climate change scenarios. A decline in 0.15 and 0.30 in ocean pH may cause an increase of the PAF by 0.04 to 0.06 and 0.12 to 0.14, respectively (based on EC_{50} results). This is the first study which uses SSDs in order to estimate global climate change impacts on ocean biota.

The issue of freshwater eutrophication is addressed in chapters 5, 6, and 7. Similarly to chapter 2, species-specific ranges (total of 2294) of total phosphorus (TP) are developed in **chapter 5** to derive RSR – TP relationships for four different climate types, i.e. cold, temperate, xeric, and (sub)tropical. In this case, the stressor – response relationships were developed separately for two species groups, i.e. autotrophs and heterotrophs, and two freshwater types, i.e., lakes and streams, to identify the sensitivity of biomes to decreases in RSR following TP level increases. Notable biogeographic patterns such as the lower optimal TP levels which maximize species richness in cold lakes compared to temperate lakes, for example, could be identified. These patterns arise due to differentiated biogeochemical and hydrologic processes to which species were subjected at an evolutionary scale.

In **chapter 6**, the PNOF of heterotrophic species as a function of TP was developed with the uppermost surveyed TP level for lakes and streams in the temperate region. The PNOF – TP functions were subsequently employed towards the derivation of three different effect models for LCIA, which describe the increase in PNOF with an increase in TP levels, in the two freshwater types (i.e. lakes and streams). These effect factors were then combined with an existing model of P transport in freshwaters to derive endpoint CFs, expressing the ecological impact of phosphorus emissions to freshwater. Freshwater type and spatial variability driven by P transport are shown as important factors influencing CF results.

In **chapter 7**, stressor – response functions were derived for potential species absences with TP and NO_3 concentrations and combined with long term monitoring data on nutrient concentrations in Europe to estimate the ecological risk (ER) that invertebrate species within a community assemblage may become absent due to nutrient stress. In this case, the ER posed by additive effects of TP and NO_3 is determined separately for lakes and streams on a yearly basis (from 1985 to 2011). Although limitations to primary productivity have been persistently attributed to P, risks of potential absences of invertebrates appear to be mainly driven by N stress. This study describes how existing concepts of ERA can aid towards the improvement of water quality required by the European Water Framework Directive.

In **chapter 8**, the primary uncertain components involved in the derivation and application of the effect models are described, e.g. the unaccountability of interacting effects among stressors and of ecological effects of declining stressor levels, among others, as well as recommendations for future work on nutrient pollution.

SAMENVATTING

Toenamen in de toevoer van nutriënten gaan gepaard met toenemende gehalten van deze stressoren in het milieu. Nutriëntenvervuiling kan de groei, reproductie en mortaliteit van soorten beïnvloeden en daardoor uiteindelijk ook de aanwezigheid van soorten en de soortenrijkdom van levensgemeenschappen. In dit proefschrift wordt de nutriëntenvervuiling geanalyseerd in drie milieucompartimenten, namelijk zeewater, zoetwater en land. In ieder compartiment is een andere milieuprobleem geanalyseerd: eutrofiering van zoete watersystemen en verzuring van terrestrische bodems en oceanen. Dit zijn en blijven zeer waarschijnlijk milieuproblemen op mondiale schaal.

Na uitgebreide dataverzameling, zijn stressor – respons relaties opgesteld om effecten van nutriëntenvervuiling op soorten of soortengroepen te schatten. Hiervoor zijn soortspecifieke effecten en daaraan gerelateerde gehalten van stressoren afgeleid uit 'peer-reviewed' literatuur. Biogeochemische processen op lange termijn, macrorevolutionaire processen en inherente soortkenmerken spelen een belangrijke rol in de gevoeligheid van soorten voor milieustress en bepalen bijgevolg de stressor – respons relaties die zijn opgesteld in de verschillende hoofdstukken van dit proefschrift. Tenslotte zijn deze relaties toegepast in milieugerichte levenscyclus effectanalyses (LCIA) en risicobeoordelingen (ERA).

In de hoofdstukken 2 en 3 wordt het thema verzuring uitgewerkt voor het terrestrische milieucompartiment en in hoofdstuk 4 voor het mariene compartiment. **Hoofdstuk 2** omvat een inventarisatie van bodem pH bereiken waarbinnen verschillende soorten vaatplanten zijn waargenomen tijdens veldonderzoeken. Vervolgens zijn deze presentiedata gebruikt voor het afleiden van de relatieve soortenrijkdom (RSR) als functie van de bodem pH in verschillende habitattypen op aarde. In totaal zijn 2409 soorten geïnventariseerd. De zuurtolerantie (pH-bereik) van iedere individuele soort is bepaald op basis van de minimale en maximale pH-waarde waarbij de betreffende soort nog is waargenomen. Logistische regressies zijn gebruikt om de gevoeligheid van habitattypen te bepalen voor afname van de RSR bij dalende pH. In dit hoofdstuk zijn biogeografische patronen geïdentificeerd, zoals de discrepantie tussen pH condities die de soortenrijkdom in habitattypen maximaliseren en de verschillen in gevoeligheid van habitattypen. (Sub)tropische regenwouden zijn gevoeliger voor daling van de pH dan andere habitattypen terwijl woestijnen en droge struwelen een hoge RSR handhaven bij tamelijk hoge pH condities.

In **hoofdstuk 3** is de cumulatieve toename van de potentieel niet aanwezige fractie (PNOF) vaatplantsoorten als functie van de bodem pH afgeleid van de minimale pH waarde die voor iedere soort is waargenomen in verschillende terrestrische habitattypen. Vervolgens zijn PNOF – pH relaties afgeleid om kwantitatieve relaties te bepalen voor marginale toename in PNOF als gevolg van marginale daling in bodem pH (in LCIA gedefinieerd als marginale effect factoren). In combinatie met beschikbare modellen voor atmosferisch transport and bodemchemie zijn eindpunt karakterisatiefactoren (CFs) voor terrestrische verzuring op mondiale schaal afgeleid voor emissies van stikstofoxides, ammoniak en zwaveldioxide. De CFs drukken milieueffecten op een ecosysteem uit per emissie-eenheid verzurende stoffen (namelijk, de toename in PNOF per emissie-eenheid). CFs zijn berekend voor verschillende ruimtelijke schaalniveaus (hoogste resolutie: 2.0º x 2.5º). De variabiliteit van CFs bedraagt circa zes ordes van grootte en wordt vooral bepaald door de variabiliteit in bodemgevoeligheid voor atmosferische depositie.

In **hoofdstuk 4** is de cumulatieve toename van de potentieel aangetaste fractie (PAF) mariene soorten die verkalken (zoals geleedpotigen en neteldieren) als functie van de water pH geschat met soortengevoeligheidsverdelingen (SSDs). Deze PAF – pH relaties zijn opgesteld op basis van experimentele data over geringe (EC_{10}) en ernstige (EC_{50}) effecten op de groei, reproductie en mortaliteit van soorten. Vervolgens zijn de PAF – pH functies toegepast in een ERA waarbij de verwachte PAF bij pH daling van zeewater is geschat voor twee mondiale klimaatscenario’s. Een pH daling van 0.15 en 0.30 in een oceaan kan resulteren in een toename van de PAF met respectievelijk 0.04 tot 0.06 en 0.12 tot 0.14 (gebaseerd op EC_{50} waarden). Dit is de eerste studie waarin SSDs zijn gebruikt om de effecten van mondiale klimaatscenario’s op organismen in oceanen te schatten.

Het thema zoetwater eutrofiering komt aan de orde in de hoofdstukken 5, 6 en 7. Conform hoofdstuk 2 zijn ook in **hoofdstuk 5** soortspecifieke milieugrenzen (in totaal 2294) voor totaal fosfor (TP) bepaald om RSR – TP relaties af te leiden voor zoetwater ecosystemen in vier verschillende klimaattypen (koud, gematigd, droog en (sub)tropisch). De stressor – respons relaties zijn in dit geval afzonderlijk ontwikkeld voor twee soortgroepen (autotrofen en heterotrofen) en twee zoetwatertypen (meren en rivieren) om de gevoeligheid van verschillende habitattypen voor afname in RSR bij toenemende TP concentraties te bepalen. Tevens zijn opmerkelijke biogeografische patronen geïdentificeerd, zoals het optimale TP gehalte voor maximale soortenrijkdom die voor meren in koude gebieden lager is dan voor meren in gematigde streken. Dergelijke patronen zijn waarschijnlijk een gevolg van blootstelling aan verschillende biogeochemische en hydrologische processen op een evolutionaire tijdschaal.

In **hoofdstuk 6** is de PNOF voor heterotrofe soorten als functie van TP afgeleid op basis van de hoogst waargenomen TP gehalten in meren en rivieren in gematigde gebieden. De PNOF – TP functies zijn vervolgens gebruikt voor het afleiden van drie verschillende effectmodellen voor LCIA, die de toename in PNOF bij toenemende TP gehalten beschrijven, in twee typen zoetwatersystemen (meren en rivieren). Deze effectfactoren zijn gecombineerd met een bestaand model voor P transport in zoetwatersystemen voor het afleiden van eindpunt CFs voor de ecologische effecten fosforemissies in die systemen. De factoren watertype en ruimtelijke variabiliteit door P transport hebben grote invloed op CF uitkomsten.

In **hoofdstuk 7** zijn stressor – respons functies afgeleid voor potentiële afwezigheid van soorten in relatie tot TP en NO_3 concentraties. Dergelijke functies zijn vervolgens gecombineerd met data van lange termijn monitoring van nutriëntenconcentraties in Europa voor de schatting van ecologische risico's (ER) zoals het verdwijnen van ongewervelde soorten uit een levensgemeenschap door nutriënten stress. De ER als gevolg van additieve effecten van TP en NO_3 is in dit geval afzonderlijk en op jaarlijkse basis bepaald voor meren en rivieren voor de periode 1985-2011. Hoewel limitering van de primaire productie vooral wordt toegeschreven aan P, blijkt het risico van potentiële afwezigheid van ongewervelde soorten vooral te worden bepaald door N stress. Dit onderzoek beschrijft ook hoe het kan bijdragen aan verbetering van de waterkwaliteit zoals vereist door de Europese Kaderrichtlijn Water.

Hoofdstuk 8 beschrijft belangrijke bronnen voor onzekerheid bij de afleiding en toepassing van effectmodellen, zoals de toerekenbaarheid van inter-acterende effecten van stressoren en ecologische effecten bij afnemende gehalten van stressoren, en geeft aanbevelingen voor toekomstig onderzoek aan nutriëntenvervuiling.

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Curriculum vitae

I was born on 28 April 1983 in São Paulo (Brazil), where I stayed until the end of high school. In 2006, I began my undergraduate studies in agronomic engineering at the Luiz de Queiroz College of Agriculture of the University of São Paulo – ESALQ. During my program, I was part of the student council and I was the editor of the student newspaper. In the last six months of 2006, I went to the University of California – Davis (the United States) at the Plant Sciences Department for an research internship on strategies to improve tomato post-harvest, from which I later wrote my B.Sc. thesis. In 2007, I returned to Davis as a laboratory tecnitian to assist on existing research projects on water quality in rice fields of the Central Valley and irrigared pastures of the foothills of California's Sierra Nevada. I started my M.Sc. program in Soils and Biogeochemistry at the same laboratory and I wrote my M.Sc. thesis on strategies for improvement of runoff water quality in irrigated pastures in the end of 2009.

In 2010, I moved to the Netherlands to start my PhD program at the Department of Environmental Science at Radboud University Nijmegen. The research I conducted during my four years in Nijmegen led me to write this thesis. During that time, I had the opportunity of being part of some of the teaching activities of the department as well as being part of the PhD student council of the Research School for Socio-Economic and Natural Sciences of the Environment (SENSE). Towards the end of my PhD work, I was part of the 2013 Young Scientists Summer Program (YSSP) of International Institute for Applied Systems Analysis (IIASA), in Austria. During that summer, I conducted additional research on environmental impact assessments, this time on the topic of land use and forest fragmentation. In 2014, the opportunity arose to go back to IIASA as a post-doctoral researcher of the Ecosystem Services and Management Program (ESM), where I am today. At the moment, I perform nutrient dynamics and crop modeling under different scenarios of phosphorus and nitrogen availability in the soils of the world.

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